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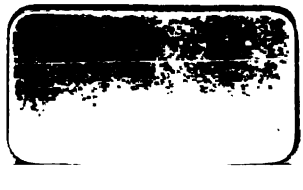

MINUTES OF PROCEEDINGS

OF THE

INSTITUTION

OF

CIVIL ENGINEERS;

WITH

ABSTRACTS OF THE DISCUSSIONS.

VOL. XVI.

SESSION 1856–57.

EDITED BY

CHARLES MANBY, M. INST. C.E., F.R.S.,
SECRETARY.

INDEX, PAGE 493.

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INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1856-57.

November 11, 1856.

ROBERT STEPHENSON, M.P., President, in the Chair.

Mr. R. Stephenson, M.P., President, on taking the Chair said, that for some time past the state of his health had been so precarious, as to render it doubtful whether he could remain in England to be present at the first meeting of the Session. He had been extremely anxious on this point, as he wished to meet the Members, before his departure on a journey, which might have a duration of at least two months, and thus cause his absence at the period of the Annual General Meeting, when the election of the Council and Officers for the ensuing year would take place. It would be remembered, that, in his inaugural address, he had thus stated his views as to the duration of the tenure of the office of President: "Referring to matters peculiar to the Institution, it is my duty, before I conclude, to mention a subject which has occupied the serious attention of your Council,—I mean the duration of the tenure of the office of President. My individual opinion on the question has been already expressed in this room, and those sentiments have undergone no change. My mission is now, however, to represent the views of the collective body, and to conform to any course which may be deemed for the general good." Still retaining these sentiments, he had been desirous of retiring at the expiration of the first year of office; it had, however, been represented to him, that such a step might be prejudicial to the welfare of the Institution, and that consideration, combined with the persuasions of the kind friends around him, induced him to abandon his previous determination, and to leave the matter in the hands of the general body. Therefore, if at the period of the election he was again honoured by the suffrages of the Members,

he should be happy to continue to preside over the Institution. If, however, he was permitted to retire among the ranks of the Past Presidents, he should still hope to be constant in his attendance at the meetings, and to take an active part in the proceedings, which he considered was an imperative duty imposed on those who had been honoured by election to the presidential chair.

He begged to thank all those gentlemen who had contributed Papers during the past year, and he expressed a hope, that they would be fully emulated during the present session. It would, perhaps, be invidious to allude to any particular Papers, but he must, nevertheless, mention Mr. Murray's excellent Account of the Sunderland Docks,[1] as deserving the careful study of all the junior members of the profession. It was replete with useful information, giving practical details of a large work which had been more than usually successful, and as an example of Dock Engineering stood almost unrivalled in this country. The system of sluicing, or of scouring the entrance, particularly deserved attention, as the volumes of water simultaneously emitted from numerous apertures, by means of Armstrong's hydraulic apparatus, possessed an almost irresistible force, sufficing for the complete removal of the accumulation of silt, sand, and débris brought by storms, or process of deposit, within the entrance channel. This mode of the application of water-power would be adopted in other positions with, he hoped, equal success.

He could not avoid also mentioning another Paper, for which he felt under peculiar obligation, as it was produced almost entirely at his personal request. He alluded to the Explanation of the System of Mental Calculation[2] which had been given by his friend Mr. Bidder, to whom he tendered his best thanks. The subject was one in which Mr. Bidder stood pre-eminent; but, however rapidly the results might be arrived at, it was by no means so easy to explain the processes. Several weeks had been devoted to the preparation of the lectures, in order to give the explanation in simple terms; but it had required much greater devotion of time and attention to reduce them to writing for publication. The difficulties had, however, been, to a great extent, overcome; the whole was now in type, and the concluding part of the volume of the Proceedings of the past year was now nearly ready for being issued.

The President again thanked the Members for their attendance, exhorted them to increased attention, and to the production of Papers for reading at the Meetings, which would be presided over by the Vice-Presidents during his absence, and cordially bade them adieu.

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[1] *Vide* Minutes of Proceedings, vol. xv. page 418.
[2] Ibid. page 251.

No. 949.—"On the Improvement of Railway Locomotive Stock, and the Reduction of the Working Expenses."[1] By DANIEL KINNEAR CLARK, Assoc. Inst. C.E.

IT is designed in this Paper, to discuss the Locomotive Engine:—to consider some departments of practice which appear to be in a transition state;—to endeavour to indicate how far, in some respects, the Locomotive, even in its present advanced state, is susceptible of improvement; and to form some estimate of the pecuniary advantages thus derivable.

The Locomotive is a compound machine, and, for purposes of useful inquiry, it must be treated as such. It is composed of three distinct elements,—the boiler, the engine, and the carriage, comprising the frame and the wheels; each element again, may be treated anatomically, with respect to its construction, and physiologically, with respect to its functions. The discussion will be confined, on the present occasion, to the physiology of the Locomotive; and, first of the boiler.

THE BOILER.—There are three important questions affecting the boiler, open for discussion, with respect to fuel, to water, and to area of fire-grate and heating surface.

First, as to Fuel.—The fuels in use in this country, are coke and coal. The best coke consists almost entirely of carbon, containing about 98 per cent. of this combustible. The heating power of carbon, when perfectly burnt, is equal to the evaporation of 12 lbs. of water, at 60°, into steam of 120 lbs. pressure, by 1 lb. of carbon. In a Paper read by the Author before the Institution in 1853,[2] it was shown, by a mechanical analysis, that the combustion of coke in the fire-box of the ordinary locomotive was practically complete, and that, therefore, nothing could be gained by the use of expedients intended to improve the combustion of coke. It is satisfactory to add that, subsequently to the reading of that Paper, these conclusions were corroborated by the results of a chemical analysis of the products of the combustion of coke, in the engines of the Paris and Lyons Railway, by M. Ebelmen;[3] he found, that under ordinary circumstances, the gases in the smoke-box consisted almost entirely of carbonic acid and nitrogen, with a mere trace of carbonic oxide, rarely exceeding 2 per cent.

[1] The tables, illustrative diagrams, and drawings referred to in the Paper may be consulted by the Members at the Institution. It will be found, that the Paper has been written so as to render their publication unnecessary.—The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

[2] *Vide* a Paper "On Locomotive Boilers," by the Author, read March 8, 1853, and published in the 'Minutes of Proceedings,' vol. xii., page 382.

[3] *Vide* the *Artizan* for August, 1853.

Coal is a compound fuel, consisting chiefly of carbon and hydrogen. The production of smoke, in the use of coal,—or the suspension of unconsumed particles of carbon,—is due to the presence of the hydrogen; because, hydrogen has a greater chemical affinity for oxygen than carbon has, and therefore, having a prior claim to the oxygen for combustion, it impedes the combustion of the carbon. This preference claim must be met, and smoke is likely to be generated, so long as any hydrogen remains to be driven off; when this gas is entirely expelled, the fuel remaining is incandescent coke, or carbon, which lies comparatively flameless and smokeless on the grate. In explanation, it must be added, that smoke owes its existence, chiefly, to the fact of the particles of carbon being, in the first place, distilled in chemical union with the hydrogen, in various proportions; and then, in the second place, is precipitated as smoke, when the hydrogen drops the carbon, and seizes the oxygen supplied by the atmosphere. The first condition of the perfect combustion of coal is, therefore, that there should be a sufficient quantity of oxygen to satisfy the prior requirements of the hydrogen of the coal, and to take up the whole of the carbon precipitated by the hydrogen.

There is a second and equally important condition, that the temperature should be sufficiently elevated to effect the union of the carbon and oxygen. Either a deficiency of oxygen, or of temperature, suffices for the production of smoke. If the hydrogen could be entirely driven off and consumed, before the carbon is separated, smoke would not be produced.

Such are, very generally, the conditions under which coal is consumed; and it will be found, that all the successful expedients for the consumption, or prevention of smoke, under stationary boilers, or elsewhere, involve the observance of the two conditions, —an ample supply of oxygen, and a sufficiently high temperature.[1]

The chief practical difficulty opposed to the fulfilment of these conditions, consists in the irregularity of the supply of fuel to the furnace; because the presence of fresh fuel lowers, for a time, the general temperature, and, also, because, in certain conditions, it impedes the flow of air through the grate. The first and most direct preventive of smoke, is a sufficiently strong draught, to insure an ample supply of oxygen, and a sufficiently high average temperature in the fire-box, to provide against the variable conditions of the elements concerned in combustion. When this remedy is not sufficient, means must be employed for equalizing

[1] The Author is indebted for his knowledge of the Chemical Conditions of Coal in process of Combustion, to an able pamphlet on the Smoke Nuisance, by the late W. M. Buchanan, of Glasgow, published by Griffin and Co., 1852.

the temperature, or at least for sustaining it above the point at which smoke is discharged.

In approaching the question of the mechanical values of fuels for evaporation, the first step should be to define, chemically, their possible maximum value, as the gauge by which their efficiency in practice is to be measured. The chemical theory of heating powers is, however, incomplete, with respect to compound fuels; for, though, no doubt, the heating powers of the main elements, carbon and hydrogen, in their combining conditions, have been determined, the former as a solid, and the latter as a gas, it remains to be established, how far the heating power of hydrogen, as a gas, represents that of hydrogen as a solid, which is the normal condition of hydrogen in coal. The hydrogen is gasefied previously to its union with oxygen, and involves the abstraction from the general fund, of as much heat as is requisite for its preparatory conversion from a solid into a gas. This element being, to the best of the Author's knowledge, as yet undetermined, he is led to disregard the theoretical heating powers assigned to various fuels by Playfair and De la Beche in their "Reports on Coals suited to the Royal Navy;"[1] and to pass on to the results of working practice.

And, first, it seems to be established in general, irrespective of locomotive practice, that, with suitable arrangements, good coal may evaporate as much water as good coke, weight for weight; so that their working evaporative powers appear to be practically the same.

Second, that coke and coal demand distinct and peculiar methods of treatment, in order to the attainment of the best results from each.

The recognition of this essential distinction, in locomotive practice, constitutes an era in the history of that wonderful machine, perhaps, the most remarkable since the introduction of the link-motion by Mr. R. Stephenson. Locomotives which are favourably adapted for the combustion of coke, are not in general favourably adapted for that of coal; and *vice versâ*. Coke burns best in heaps, coal in layers. Coke being simple, is instantly burnt; coal being compound, requires time for its complete conversion, the hydrogen first, the carbon afterwards. The inference, then, is, that a restricted grate and concentrated combustion are the most favourable for the conversion of coke; whilst a larger grate and plenty of fire-box room are the best for coal. For the larger grate, a more moderate draft is required, and it therefore gives more time and opportunity for the mixing and conversion of the

[1] *Vide* "First, Second, and Third Reports on Coals for the Navy." By Sir H. De la Beche and Dr. Playfair. Folio. Lond. 1848–49–50.

gases concerned in combustion, which is further promoted by the larger capacity of the fire-box behind the flue-tubes.

Experimental Evidence.—In the years 1850 and 1851, the Author made various comparative trials of the combustion of coke and coal, in the ordinary forms of locomotive-boilers, on some of the Scottish railways, since published in his work on Railway Machinery; from which he concluded, that in the prevailing type of boilers, the evaporative powers of good coal and good coke, were as 2 to 3, coal doing, mechanically, just two-thirds of the duty of coke.[1]

Subsequently, in the year 1854, Messrs. E. Woods and W. P. Marshall tried the comparative mechanical values of coal and coke, in the engines of the Southern Division of the London and North-Western Railway. The engines selected for trial were, one constructed on Mr. McConnell's system, No. 303, with large fire-box, mid-feathers, and combustion chambers; and one of the 'Bloomer' class, No. 293, with an ordinary boiler, of inferior proportions. The trials were made with Pease's West Coke, and Hawksbury Coal, from Coventry, hard, clean, and free from clinker. The results were as follows:—

In the former, the prevention of smoke from coal was very completely attained, and the evaporating values were:—

1 lb. coke to 8·65 lbs. water.
1 lb. coal to 5·83 lbs. water.

Showing the ratio of coal to coke, in mechanical values, to be as 100 to 148, or as 2 to 3 nearly.

In the 'Bloomer' boiler, smoke was generally observable, and was sometimes objectionable; and one pound of coal evaporated the low quantity of 4·52 lbs. of water.

The results from Mr. McConnell's boiler corroborate the Author's results from ordinary boilers, as they indicate the same proportions of efficiency between coke and coal; and they show, that though this boiler prevented smoke, it was not more efficient in the combustion of coal than ordinary boilers. The performance of the 'Bloomer' class of boiler, above quoted, is much below the average of ordinary boilers, and cannot therefore be taken as a datum for comparison.

Mr. Crampton's step-grate for burning coal, is stated to be working well in France. The Author is not in possession of any results of the evaporative efficiency obtainable by the step-grate, and is not in a position to form any opinion of it. It has been tried on the Great Northern Railway.

In the beginning of the present year, 1856, the Author was

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[1] *Vide* "Railway Machinery," by D. K. Clark. 4to. Pages 156 to 164.

enabled to make several trials of one of Mr. Joseph Beattie's passenger-locomotives, the 'Canute,' on the London and South-Western Railway. (Plate 1.) The fire-box is large, and is divided transversely into two compartments by a mid-feather. There is a combustion chamber in the barrel of the boiler, terminating in flue-tubes which proceed to the smoke-box. The back compartment of the fire-box is arched over with fire-bricks placed at intervals apart; the combustion chamber, also, is stocked with a faggot of perforated bricks placed at some distance clear of the tubes. Through these bricks the gases of combustion must pass on their way to the tubes; they receive and retain a portion of the heat from the passing gases, when the fuel is incandescent and smokeless, and give it out to the smoke discharged from the fresh coal; thus acting as equalizers of temperature, for the purpose of consuming the smoke. The feed-water heating apparatus is in two parts, placed within and above the smoke-box; when in operation, steam from the blast-pipe is exhausted into the condenser above, where it meets the jet of cold water thrown in by one of the pumps, and is condensed by it; the feed-water, thus heated, flows back into the tender, except what is intercepted by the other pump, with which a junction is made from the return flow-pipe, for supplying the boiler. The water sent into the boiler passes, on its way, through the surcharging-chamber in the smoke-box, where it acquires a further increase of temperature, previous to entering the boiler. The surcharging-chamber contains a number of tubes for heating surface; it is supplied with heat from the exhaust steam, which is thrown directly into it from the exhaust-pipes, on its way to the condenser. Thus, when the engine is at work, the feed-water is heated, by the first process, to, or near, the boiling point, and by the second process to some point above that, having some relation to the initial temperature of the exhaust steam. The superfluous feed-water, discharged from the condenser, returns to the tender, and raises the general temperature within it.

The following are the particulars of the 'Canute' passenger-engine—

Cylinder, 15 inches diameter, 21 inches stroke.
Driving-wheel, 6 feet 6 inches diameter.
Fire-box, inside dimensions—
- Length, 4 feet 11 inches.
- Breadth, 3 feet 6 inches.
- Depth at back, 5 feet 1 inch.
- Ditto at front, 4 feet 1 inch.
- Combustion-chamber, 3 feet 6 inches diameter, flat-roofed, 4 feet 2 inches long.

Tubes, 373 in number—
Outside diameter, $1\frac{1}{4}$ inch.
Clearance between, $\frac{7}{16}$ inch.
Length between plates, 6 feet.
Ashpans, entrance, 3 feet $6\frac{1}{2}$ inches long, 12 inches deep a the front, and $9\frac{1}{2}$ inches deep at the back.
Fire-grate, in two parts, 16 feet total area.
Heating surface, interior:—

Fire-box . .	107 square feet.
Combustion-chamber	37 ditto.
Tubes . . .	625 ditto.
Total . .	769 square feet.

Fire-bricks—
Gross weight, $5\frac{3}{4}$ cwt.
Heating surface of bricks, in contact with smoke, 80 square feet.

To find the ordinary quantity of heat contained in the fire-bricks when at work, one of each form of brick was heated to the usual degree of redness, in an ordinary furnace, and plunged into a large vessel of cold water. The observed amount by which the temperature of the water was raised was multiplied into the quantity of water, and by the number of bricks of each form; and showed that the bricks contained upwards of 300,000 units of heat, equal to the heat derivable from 22 lbs. of carbon, which would evaporate 3 cubic feet of water.

The trials with the 'Canute' were designed to test the performance of the engine, with the usual express trains; and to measure the economical advantages of the fire-bricks as smoke-consumers, and of the feed-water heating apparatus. The engine was therefore tried under various conditions. 1st. In its usual order, with coal, bricks, and hot feed-water. 2nd. With coal, bricks, and cold water. 3rd. With coke, bricks, and hot feed-water. 4th. With coal, and hot feed-water, but without the bricks.

The coal used, was of three kinds, Welsh, Griff, and Stavely. The first is rich in carbon, and is known as smokeless steam-coal. The second and third burn with considerable flame and smoke. The coals were delivered to the engine, usually in equal quantities, of one-half of Welsh coal, and the remainder of Griff and Stavely coal. The water supplied to the engine was clean and hard; it was neutralized by an allowance of muriate of ammonia put into the tender.

The performance of the engine with respect to the prevention of smoke, was completely successful. Under all circumstances, there was not, at any time, the slightest vestige of ordinary coal-smoke

from the chimney-top. The engine did not require more than ordinary care and attention in manipulation, as the bricks were fully competent to the prevention of smoke.

To test the utility of the bricks as smoke-preventers, they were entirely withdrawn from the boiler in some of the trials; and, without them, the smoke emitted was of a brown colour, and occasionally in such quantities as would certainly be called a nuisance. On restoring the bricks, for the succeeding trials, the smoke vanished, and the light gases discharged from the chimney, when the steam was not admitted, had precisely the appearance of the vapour from burning coke. Economically, the bricks were found to be of utility, as the evaporative power of the coal was, by its more perfect combustion, materially greater with, than without the bricks; and the performance also was better.

The trials with coke alone, as fuel, showed, by a marked contrast, the superiority of the arrangements of the boiler for burning coal, as the evaporative power and performance of coke of excellent quality, was, contrary to all ordinary experience, decidedly inferior to that of coal.

The trials with the feed-water heating apparatus were conclusive. The engine was worked for one double trip, without the use of the heating apparatus, pumping cold water from the tender in the usual way. On these occasions there was a decided increase in the consumption of fuel.

There is much more that is worthy of remark in the tabulated results of these trials, but the limits assigned to this Paper, prevent more than a brief summary of the results from being recorded. In the following summary, an allowance of $1\frac{1}{4}$ cwt. of fuel for each double trip, is made for getting up the steam,—equal to nearly 1 lb. per mile,—and also a deduction for fuel and water consumed in running empty miles.

First, with the regular express train, and the engine in regular working order:—The average train consisted of $10\frac{1}{2}$ carriages, estimated to weigh about 66 tons, making, with the engine and tender weighing 33 tons, a gross load of 99 tons. The average speed, exclusive of stoppages, was about 34 miles per hour. Whilst running, the quantity of water evaporated, was at the rate of 82 cubic feet per hour of the time the steam was on the piston, and the blast was in operation. The quantity of coal consumed, was 547 lbs. per hour whilst under the blast. The consumption of coal was at the rate of 15 lbs. per train mile; and at the rate of ·15 lb. per mile per ton of gross load. The water evaporated per pound of coal was 9·35 lbs. The average temperature of the feed-water was 187°.

Second, with the special weighted train, and the engine in regular working order:—The train consisted of 28 carriages,

loaded to weigh 203 tons; making with the engine and tender 236 tons gross. The average speed, exclusive of stoppages, was 30¾ miles per hour. The quantity of water evaporated was at the rate of 130 cubic feet per hour, whilst under the blast. The quantity of coal consumed was at the rate of 915 lbs. per hour whilst under the blast; and at the rate of 28¾ lbs. per train mile, or ·122 lb. per mile per ton of gross load. The water evaporated per pound of coal was 8·87 lbs. The temperature of the feed-water was 212°.

Third, recurring to the performances with the regular express trains; when the fire-bricks were withdrawn from the boiler, the consumption of fuel per ton per mile was ·17 lb., and one pound of coal evaporated 8·25 lbs. of water. The corresponding quantities, with the bricks, were ·15 lb. and 9·35 lbs.; showing a direct advantage of 12 per cent. in the consumption of fuel, and indirectly, a similar advantage, in its superior evaporative efficiency, due to the use of the bricks.

When coke was used, instead of coal, the consumption was ·20 lb. per ton per mile, and one pound evaporated 7·35 lbs. of water; indicating, in this particular class of engine, a direct advantage in favour of coal, of 25 per cent. in consumption, and indirectly an advantage of 21½ per cent. by evaporative efficiency.

When the feed-water heating apparatus was disconnected, the consumption was ·224 lb. per mile per ton, and one pound of coal evaporated 8·24 lbs. of water: indicating, directly, an economy of fuel, due to the heating apparatus, of 33 per cent. in consumption, and, indirectly, 12 per cent. of economy, by increased evaporative efficiency.

The observed difference in evaporative efficiency introduces the subject of the damper, which is an important adjunct, materially affecting the efficiency of the fuel. The inferior evaporative efficiency observed when using cold feed-water, is probably due to the dampers remaining wider open, in order to keep up the steam, and so passing an excess of air. It may be also due, to some extent, to the loss of surplus heat, imparted to the heated feed-water in passing through the heating-chamber inside the smoke-box.

Deducting the gain ascribed to the better use of the dampers, from the total gain, the balance, (21 per cent.,) would represent the gain by the use of the heating apparatus; and by a little calculation would be shown to indicate a high ratio of efficiency. Thus, if the ordinary temperature at the time of the trials be taken at 50°, and the temperature of the exhaust steam be taken as that due to its mean pressure, which may be 20 lbs. per inch, as the usual initial pressure of exhaust was found by indicator diagrams to be from 30 lbs. to 40 lbs., the mean temperature of the exhaust steam in the body of the blast pipe would be 260°; and the whole

increase of temperature of the feed-water, on delivery to the boiler would be (260°−50°), or 210°. Now, the total heat of 100 lbs. of steam is 1217°; and (1217°−50°), or 1167°, is the whole amount of heat consumed in raising cold water of 50° into steam of 100 lbs. pressure. Then 1167° ÷ 210° = 5·6 nearly, and the economy of fuel would be 1−5·6 lbs. of the total, or 18 per cent.

In forming a comparison of the performance of Mr. Beattie's engine with that of other engines in which coal is used as fuel, the evaporative efficiency of the fuel in the latter may fairly be expressed by 6 lbs. of water per pound of coal, whilst the former engine evaporated 9·35 lbs. of water per pound of coal; showing a superior evaporative efficiency of 3·35 lbs., representing an economy of fuel, equal to 36 per cent.

Comparing Mr. Beattie's engine then, as a coal-burning engine, with professed coke-burning engines, it is on a footing of equality with them, in evaporative efficiency of fuel, weight for weight.

By the employment of the feed-water heating apparatus, and by the more efficient use of the damper, in conjunction with that apparatus, an economy of fuel, equal to 20 per cent., may safely be assumed, relatively to the consumption of fuel with cold feed-water.

The economical evaporative power of the boiler of the 'Canute,' in terms of the grate-area and the heating surface, is equal to 51 cubic feet of water per hour, according to the formula,

$$c = \cdot 00222 \left(\frac{h}{g}\right)^2$$

deduced by the Author from his observations with coke as fuel; in which c, is the consumption of water in cubic feet per hour, at the rate of 9 lbs. per pound of fuel, h is the total inside heating surface in square feet, and g is the grate-area in square feet. A greater evaporative performance can only be attained through a partial sacrifice of fuel. It was accordingly found on trial, that the 'Canute' in evaporating, with excellent coke, 87 cubic feet of water per hour, which is considerably in excess of the economical maximum, 51 cubic feet, did so with a loss, at the inferior rate of 7·35 lbs. of water per pound of coke.

Whereas, by a remarkable contrast, water was evaporated in much greater quantities by coal, and with greater economy of fuel:—thus 82 cubic feet of water per hour were evaporated at the rate of 9·35 lbs. per pound of good coal, and 130 cubic feet per hour at the rate of 8·87 lbs. per pound of coal, or nearly 9 lbs., which is the assumed economical standard.

It may be inferred, that the economical evaporative power of the boiler of the 'Canute,' is about 2½ times as great, with good coal, as it is with good coke; and that, though detailed and continuous experiments are wanting, to complete the investigation of

the question of coal-burning *versus* coke-burning engines, the conditions most favourable for the two classes of boilers, are radically different. The coal-burner appears to require a large grate, and a large atmosphere in the fire-box; whereas it has been found, by the Author, after extended inquiry, that the coke-burner requires, for the greatest efficiency of the fuel, a moderate grate and a moderate atmosphere.

To compare the performance of the outside-cylinder coal-burning engine, with ordinary outside-cylinder coke-burning engines, the Author adduces some of the results of trials made by himself, on the Caledonian Railway in 1850, with an express engine, and also the results of experiments by Messrs. Woods and Marshall, on the London and North-Western Railway, in 1853.

It appears, First. That the Caledonian engine used the same fuel per mile to do only 60 per cent. of the gross duty performed by the South-Western engine. Secondly. That the North-Western outside-cylinder engine, drawing nearly the same gross load, 96 tons, consumes double the weight of fuel used by the South-Western engine. Thirdly. That the two North-Western outside-cylinder engines, taking a heavy load of 227 tons gross, consumes 53 per cent. more fuel than is used by the South-Western engine; the speed, however, being greater by 4 miles per hour, whilst the load is less by 9 tons. These comparisons are made between the duty of coal in the South-Western engine, and that of coke in the other engines. If the gross consumptions in the South-Western engine be compared with the other results, it would compare of course less favourably than in the preceding results; but the data are wanting to make a more specific comparison.

Second, as to Water.—The quality of the water supplied to locomotive boilers has much influence on their efficiency. The water is seldom pure: it commonly holds in suspension mineral, vegetable, or animal matters, which are precipitated and deposited upon the heating surfaces of the boiler, impairing its evaporative power and economy, and destroying the material; or, if muddy in character, causing priming of water with the steam, which ends in results equally prejudicial to the durability of the working parts, and to the efficiency of the engine.

Calcareous deposits are the most common in locomotive-boilers, and, in extreme cases, they have been observed to shorten the duration of the fire-boxes to a few months. In Ireland, the contrasts afforded by the use of hard water from calcareous soils, and of soft water from boggy soils, in neighbouring districts, are instructive; for whereas the hard water has been known to terminate the useful existence of the fire-box and tubes of boilers within three years, the boilers fed with bog-water have lasted in good order for eight or nine years.

The injury inflicted upon those parts of the machinery working amongst the steam raised from bad water, as the valves, pistons, and glands, is also considerable; for grit and mud are carried over in suspension, and accelerate the wear of such parts.

The direct loss of heat by priming also, is considerable. Fresh water will prime over, to the extent of 30 per cent. of the total water consumed. Without at present taking into account the loss by back pressure of exhaust on the piston caused by priming, the loss of heat by priming, as above, is 9 to 10 per cent. of the whole heat thrown into the boiler.

Upon the whole, the Author is of opinion, that at least 10 per cent. of the working charges affected by the quality of the feed-water, due to bad water, may be economised by the use of good water. In this deduction he is corroborated by Mr. Forsyth, of Manchester, who states that he feels safe in estimating an economy of at least 12 per cent. in fuel and wear and tear of parts affected.

This leads to the question of a uniformly good water-supply to locomotive boilers. The answer seems simple and obvious:—purify the water before its admission into the system, by filtering beds in the case of mechanical impurities; or, for chemical impurities, by the application of chemical antidotes on a large scale, in the tanks, or reservoirs, holding the water in store. The Author suggested this course in 1853, and he believes it has recently been brought into practice with beneficial results. For the removal of chemical impurities, there is no universal medicine; every quality of water must be analysed, and prescribed for individually; and the Author is informed that this can be done at a very small cost. [1]

Third, as to the area of Fire-grate and Heating Surface.—This question was discussed at length, by the Author, in his Paper of 1853, [2] and from the experiments and observations therein detailed, he concluded that the grate-area should be proportioned to the heating surface, as well as to the evaporative power, in order to insure the most economical performance. These deductions were based upon data derived from the use of coke as fuel; and, no doubt, they apply likewise, in their general acceptation, to the practice with coal. But, in their application to the use of coal, it has been indicated in an earlier part of this paper, that the special proportions most suitable for coal, are different to those for coke; and it remains a matter for future trial and observation, to determine, comprehensively, the conditions of the best performance of coal in locomotives.

Of the Engine.—The engine proper is the dispenser of the

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[1] *Vide* a Paper "on Water for Locomotive Engines, and its Chemical Analysis," by W. West. Min. Proc. Inst. C.E., vol. v. page 182.

[2] Ibid. vol. xii. page 382.

steam-power from the boiler, and comprises the cylinders, pistons, driving wheels, and gearing. The general conditions of best action are, that the steam should be freely admitted into the cylinders, and be freely exhausted; that it should be efficiently worked by variable expansion gear; and that it should be well protected from condensation by exposure. It may be added, that the steam should be not merely protected, but superheated also.

The Author regrets that, within the limits of this Paper, he can scarcely adduce evidence at length on these points. In place, therefore, of bringing forward his most recent observations on the action of steam in the cylinder, he takes the liberty of noting his conclusions from observation and experience, on that subject, abstracted from his work on Railway Machinery:[1]—

Expansive-working in locomotives, can be done well and economically by means of the link-motion. The steam may be admitted freely, and expanded sufficiently; it may also be exhausted freely, as, by a suitable arrangement of the smoke-box and the blast-pipe, back exhaust pressure on the piston can be entirely removed. Expansion may be carried by the agency of the link-motion to 8 times; that is, the steam may be cut off at 1-8th. In exposed cylinders, the condensation of steam by exposure is considerable, the per-centage increasing with the degree of expansion, until, in cutting off at 1-8th, the loss may amount to 60 per cent. of the whole steam admitted into the cylinder. Incidentally, outside cylinders are more exposed than inside cylinders; and, therefore, in the former, the condensation is generally greater than in the latter; this explains how, in popular language, outside cylinders are said to prime more than inside cylinders.

The remedies for this state of things are, to protect the cylinders from external cooling, and to superheat the steam, either on its way to the cylinders, or while it is within the cylinders, by external application of heat. The additional supply of heat is beneficial, also, in evaporating the water which, more or less, primes over with the steam from the boiler.

The saving of fuel realisable by such means, should be, at the lowest estimate, 10 per cent.; it might and probably would be, much greater, if applied in the best manner.

There is, in general practice, a deficiency of accommodation for working steam so expansively as it could be worked with advantage, owing to the limited dimensions of the cylinders. The average period of admission of steam into the cylinders, even on light duty, is, in ordinary practice, as much as from 40 to 50 per cent. of the stroke, showing that the practice of expansive-working in loco-

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[1] *Vide* "Railway Machinery," by D. K. Clark. 4to. Pages 97, 119, and 120.

motives, is open to improvement. There is no great difficulty in arranging, for general practice, to cut off at least as early as at one-fifth of the stroke, which, according to the conclusions arrived at, by the Author in 1852, would economise 25 per cent. of the fuel consumed for an average period of admission of four-ninths of the stroke.

The pressure of steam on the backs of the slide-valves, causes considerable resistance to motion. Unbalanced slide-valves ought to be superseded, by the application of means for preventing the incumbent pressure. If an inference may be based upon the co-efficient of friction between cast iron and brass, which is about one-fifth of the pressure, the resistance of an ordinary valve of 120 square inches area, under 100 lbs. steam, would be about 1 ton. With an average travel of 4 inches, and $5\frac{1}{2}$ feet driving wheels, the resistance of two such valves would be represented by 185 lbs. traction at the rails, or $1\frac{1}{4}$ lb. per ton, of a gross average load of 150 tons, equal to 6 per cent. of the whole power required to draw the train at 30 miles per hour, allowing a resistance equal to 20 lbs. per ton gross.

The important results recently obtained by Mr. C. W. Siemens, from his Regenerative Engines, must be remarked. These engines consist of three cylinders, and the principle of their action is, that a given volume of steam is alternately expanded and compressed, and is, simultaneously with these changes, superheated and reduced to its normal state of saturation. Thus, the duty of the fuel consumed, is only to replace the heat directly absorbed, in expansion behind the working pistons:—the latent heat of the steam, which constitutes by far the greater proportion of heat expended in ordinary steam engines, is preserved, and a corresponding economy is effected, amounting practically, it is said, to more than two-thirds of the fuel consumed by the best engines at present in use.

Of the Carriage.—In the design of the carriage, it is required, that a sufficient weight should be placed on the driving wheels to insure adhesion, and that the machine should run freely and steadily at all speeds.

Various circumstances operated to render the earlier classes of engines unsteady:—a short wheel-base, the overhanging masses, and the unbalanced revolving and reciprocating masses of the crank, with the piston and its appendages. The evils were aggravated with outside, as compared with inside cylinders, on account of the greater spread laterally of the swinging masses. These evils were sought to be remedied by various expedients:—the extension of the wheel-base, lowering the boiler, loading the foot-plate behind the fire-box with cast iron, coupling the engine very stiffly to the tender, the use of three balanced cylinders, stiffening

the frame, and the most prominent expedient of all, placing the driving wheel behind the fire-box. On the system of the hind drivers, the load was necessarily placed almost entirely upon the extreme axles, fore and hind, to insure a sufficiency of driving weight; it followed that the horizontal leverage of the wheels with their loads, and their resistance to horizontal sinuous motion, were increased, in so far as a greater disturbing force is requisite to sway an engine about one of its extreme axles, than about a central axle; and superior steadiness was obtained. This system, however, though it removed instability externally, left the swinging masses unbalanced; it also involved a longer wheel-base, and a heavier engine, than on ordinary plans.

The distinguishing features successively adopted in the construction of Locomotive Engines are so well known as scarcely to require description, but it may be well to allude to them succinctly.—The form of engine primitively adopted in the 'Planet,' by Stephenson, was with four wheels and inside cylinders. This arrangement was succeeded, in Stephenson's practice, by an engine with a third pair of wheels behind the fire-box, to check the vertical pendulous movement of the engine. Expansions of this normal arrangement were, the inside-cylinder engines of Sharp, Wilson, Kitson, Bury, Stephenson, Hawthorn, and Gooch. The course of improvement and alteration in the arrangement of outside-cylinder engines, was taken up by Stephenson, Stirling, Allan, J. V. Gooch, Crampton, and Adams. An adaptation of driving wheels behind the fire-box, to inside cylinders was made; and Stephenson's method of hind drivers was applied, by Mr. Adams, to light tank engines on four wheels. The position of the centre of gravity, horizontally, in each of the engines, may be deduced by a simple process from the loads on the wheels.

The remarkable uniformity with which the leading idea of a central driving axle, in front of the fire-box, initiated by Stephenson, is adopted by almost all the others, will be noticed. The reasons which led to this uniformity of practice are not difficult of appreciation, and they are worth some consideration, as bearing on the general question of single-wheel engines. In the first place, there is the demand for a sufficiency of driving weight, to supply the required adhesion for traction; but the apportioning of the driving weight to one pair of wheels, must be executed with a regard to the requirements of the others, which are carrying wheels simply. The function of the front wheels is to lead the engine, and that of the hind wheels, as carriers, is mainly to steady it; thus, the front wheels require a greater load than the hind wheels, but not so much as the drivers; and the drivers stand first, the leaders next, and the trailers last in the order of loading.

It naturally follows that for the driving wheels of single engines,

the best situation is at some little distance behind the centre of gravity of the whole machine, because the supply of load to the driving wheels in that situation, is the most direct; and, in the adjustment of the driving load, the loads on the other wheels are individually less affected than when the drivers are far from the centre of gravity.

It might be said, as a precautionary suggestion, with reference to the system of central driving wheels, that they should be placed some distance behind the centre of gravity, to insure a sufficiency of weight on the leading wheels. This condition is easily met in practice, because, conveniently enough, the centre of gravity of ordinary engines is situated 3 to 4 feet in advance of the fire-box, and there is room for the driving axle behind it.

Whereas, when the driving axle is behind the fire-box, the centre of gravity lies mid-way between the extreme axles, and there is as much weight imposed, unnecessarily, but unavoidably, on the leading, as on the driving wheels. Hence the first objection to the system introduced by Mr. Crampton, a deficiency of driving weight, or the alternative, an extra weight of engine. Comparing that engine with those introduced by Mr. Bury:—the gross weight of the former is 27 tons, of which $11\frac{1}{2}$ tons rest on the front axle, $11\frac{1}{2}$ tons on the driving axle, and 4 tons on the middle axle; the gross weight of Mr. Bury's engine is $20\frac{1}{2}$ tons, of which there are 12 tons driving weight, 6 tons leading, and $2\frac{1}{2}$ tons trailing. Thus, with equal driving weights, which ought to mean equal powers, Mr. Crampton's engine is $6\frac{1}{2}$ tons heavier than Mr. Bury's.

In Mr. Crampton's engines, again, the load being thrown mainly on the extreme axles, the engine runs heavily and severely along curves; which is proved in practice by the greater wear of the leading wheel-flanges in them, than in ordinary engines.

Moreover in this system, an injurious extension of wheel-base is incurred, through the necessity for placing the leading wheels far forward, to relieve them as much as possible, of what is, to them, superfluous load. The labour of passing along curves also increases with the extension of the base.

All these objections are avoidable in the ordinary system with central driving wheels; and this system only wants maturing to make it quite satisfactory as a carriage. The one primary and sufficient condition is, that the revolving and reciprocating masses of the pistons, piston-rods, cross-heads, connecting-rods, and cranks, should be balanced in the wheels. This condition was pointed out ten years ago, by Mr. Stephenson, in his evidence before the Gauge Commissioners, in 1845; and he at the same time exposed the fallacy, that the action of the steam on the pistons had anything necessarily to do with unsteadiness. "When the steam presses upon the piston," he says, "it at the same time presses against

the lid of the cylinder; the action and reaction must be equal. Therefore I do not believe that it is the steam that causes the irregular action, but I believe it to be the mere weight of the pistons themselves, and, if we could contrive to balance the pistons by the weight upon the wheel, we should get rid of that very much."[1] A complete balance can be effected, and it has been done by the Author, for the first time in this country, so far as he is aware, in the outside-cylinder engines of the Great North of Scotland Railway, designed by him. These engines run with absolute steadiness, at the highest speeds attained on that line, without the least internal disturbing action of any kind.

All classes of engines, with inside, or outside cylinders, single, or coupled wheels, may be satisfactorily balanced on the principle above indicated. In general, however, the locomotive stock of this country is very imperfectly balanced.

Experimental Evidence.—As the wear of the leading wheels of engines may be accepted as an index to the labour of running, the Author produces a comparative statement of the working of three classes of express engines, on the North British Railway, showing the usual number of miles run by the leading wheels of each class, until they require re-turning; also the nature of the wear of these wheels:—

Ordinary express engines, with inside cylinders, unbalanced, ran 8,500 miles; they were turned up on account of the flanges wearing thin, in nine cases out of twelve.

The 'Queen,' express engine, with inside cylinders, unbalanced, ran 7,000 miles; it was turned up on account of the flanges wearing thin.

Mr. Crampton's engine ran 6,000 miles, and was also turned up on account of the flanges wearing thin.

Thus, the 'Queen' engine ran its leading wheels, 17 per cent. more miles than Mr. Crampton's; and the ordinary express engines 42 per cent. more miles; notwithstanding that Mr. Crampton's engine ran much more steadily than the other two. The cause of the inferior duration of Mr. Crampton's leading wheel-tyres, is to be found in the extra labour of running round curves.

Economy of fuel is materially promoted by the correct equilibration of engines. With Mr. Beattie's permission, the Author recently balanced the 'Canute' engine, to supply an example. This engine had previously a balance-weight of 85 lbs. applied within the rims of the driving wheels. New weights were put in, weighing 186 lbs. for each wheel, and balancing the whole mass, acting at the crank-pin. The engine ran so much more steadily

[1] *Vide* Report of the Gauge Commissioners, 1846; Minutes of Evidence, page 18.

and freely with the new balance-weights, as to take the engineman by surprise; on the first day after the alteration, it considerably overshot the stopping stations.

In working the main-line trains, the average performance of the 'Canute,' taken from the Company's books, was as follows:—For four months, ending January 30, 1856, she took an average train of 12 carriages with 20·9 lbs. of coal per mile. Early in February the balance-weights were inserted, and subsequently up to March 26, 1856, she took an average train of 10·6 carriages, with 17·9 lbs. of coal per mile. The subsequent average train was thus less by 1·4 carriages, and the fuel was less by 3 lbs. per mile. Making an allowance of ·15 lb. of coal per ton, which, at $6\frac{1}{4}$ tons per carriage, would be 1·3 lbs. per mile, there remains an economy of 1·7 lbs. of coal per mile, due to the extra balance-weights. But this does not adequately represent the economy, because the weather subsequently was much more severe than previously to the equilibration. Accordingly, the total average performances of three other main-line passenger-engines, during the same periods, which were in the same condition as to equilibration throughout, show, that the average trains fell from 11 to 10 carriages, and the consumption rose from 19·3 lbs. to 20·8 lbs. of coal per mile. Allowing for the difference of trains as before, the equivalent consumption in the second period would be 21·8 lbs., and the increase would then be 2·5 lbs. per mile, representing the increased severity of the weather. Adding this to 1·7 lb., the saving already ascertained, the sum, 4·2 lbs. per mile, represents the presumable saving in fuel, due to the complete equilibration of the 'Canute,' amounting to 20 per cent. of the original consumption. As this deduction is based on a rather circuitous process of reasoning, only one-half, or 10 per cent., will be adopted as the presumable saving.

The 'Norman,' an outside-cylinder coupled goods-engine, on the South-Western Railway, was also equilibrated according to the plans of the Author. Such engines, unbalanced, are the most unstable of all, and the saving by equilibration should be all the greater. The engine and tender were taken alone, on a trial run, with the balance-weights complete, and they ran at speeds of more than 60 miles per hour, with perfect steadiness, excepting the disturbances due to the road, there not being the least oscillating motion of any kind. The counter-weights were then taken out of the wheels, and the engine and tender again ran out alone; but so violent was the oscillation of the engine, both laterally and fore-and-aft, and so violent also the concussions between the engine and the tender, that the engineman could not venture to exceed a speed of about 20 miles per hour; and two strong hooks between the engine and tender, were successively broken across, owing to the lurches of the engine.

CONCLUSION.—The economy of working expenses due to the improvements described, may be estimated on the following assumptions:—First, that the consumption of fuel may be accepted as an index to the working charges generally of locomotive stock. This principle was maintained by the late John Gray, in 1845,[1] and was at that time confirmed by the experience of the Manchester and Leeds, and other railways.

Second, that the average costs per ton of coal and coke, for locomotive purposes, are as 2 to 3 generally.

Economy with respect to the Boiler.—The successful substitution of coal for coke, which has been found to be equally efficient, weight for weight, reduces the cost for fuel 33 per cent. The use of an efficient feed-water heating apparatus economises generally 15 per cent. of the fuel. The use of pure feed-water instead of the ordinary unprepared waters, may economise 10 per cent. of fuel.

Economy with respect to the Engine.—The thorough protection of the cylinders, and superheating of the steam, may economise, at least 10 per cent. of fuel. Accommodation for promoting the expansive working of steam, may economise 25 per cent. of fuel.

Economy with respect to the Carriage.—The correct equilibration of the engine, to insure steady running, economises 10 per cent. of the fuel, consumed by an unbalanced engine. This may be accepted as an average result; because, for inside-cylinder engines, the saving would be less, and for outside-cylinders, and coupled wheels, it would be more.

Putting together, by a process of compound reduction, these items of economy, it appears that by purifying and heating the feed-water, by superheating the steam, and protecting the cylinders, by greater expansive-working, and by correct equilibration of the engine, a joint economy of about 54 per cent. may be effected. Further, by substituting coal for coke as fuel, and properly burning it, a reduction of 33 per cent. in cost of fuel may be effected. The cost of fuel may be averaged at one-third of the total locomotive charges, and a reduction of 33 per cent. in cost, is therefore equivalent to a reduction of 11 per cent. of the total charges. Applying this reduction, there is a gross resulting economy of 58 per cent. of the locomotive charges. A reduced economy of 50 per cent. may

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[1] "It has been found by different Companies, that the wear and tear of the engines generally, is nearly in a direct ratio with the consumption of fuel. The Manchester and Leeds Company have paid particular attention to that; and they find that their wear and tear follows nearly in a direct ratio. Of course, it cannot affect the wear and tear of the tyres, and several other parts; but the increased wear and tear on such parts as it does affect, seems to be a set-off for it; and it follows very nearly as a general rule that the wear and tear of the engine is nearly in proportion with the consumption of fuel."—*Report of the Gauge Commissioners*, 1846; *Minutes of Evidence of Mr. John Gray*, Q. 2177, p. 132.

thus be accepted as the probable gross average saving that may be effected in the consumption of fuel, and generally in the working charges of the locomotive stock of the railways of the United Kingdom.

According to a recent publication by Mr. Chattaway,[1] the average cost of locomotive power is 13·66 per cent. of the receipts. The estimated saving would, therefore, amount to about 7 per cent. on the receipts. It may, further, be inferred from the statements in that book, that the average apportionment of the receipts on the railways of this country is as follows :—

Working charges	46½ per cent.
Interest on Guaranteed Capital .	28½ „
Dividends in respect of Ordinary Shares	25 „
Gross Receipts	100

The estimated saving, 7 per cent. would, to that extent, reduce the working charges, and raise the available dividend on ordinary share capital, from 25 to 32 per cent. of the gross receipts ; or, as, according to Mr. Chattaway, the average dividend on ordinary share-capital, is 3·14 per cent. per annum, it would be raised, according to the above estimate, to 4 per cent. per annum.

The Author acknowledges the incompleteness of this investigation ; but as his object was chiefly to direct the attention of Engineers to the saving that may yet be effected in the working of locomotive stock, he hopes his communication may be found to possess some utility.

The Paper is illustrated by numerous tabular statements and diagrams.

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[1] *Vide* Railways, their Capital and Dividends, 1855-56.

[Mr. JAMES KENNEDY,

Mr. JAMES KENNEDY, (Liverpool,) through the SECRETARY, said that there were two, or three points, touching the history of the locomotive, which, in his opinion, had been inaccurately stated in the Paper. It was stated,[1] that, "The form of engine primitively adopted in the 'Planet,' by Stephenson, was with four wheels and inside cylinders. * * * Expansions of this normal arrangement were, the inside-cylinder engines of Sharp, Wilson, Kitson, Bury, Stephenson, Hawthorn, and Gooch." This, Mr. Kennedy submitted, was not correct. Having taken an active part in planning the engines for the Stockton and Darlington Railway in 1824, under the late Mr. George Stephenson, and having from that time until recently been practically engaged in the construction of locomotive engines, he was cognizant of all the improvements which had been successively introduced. The plan of constructing locomotives with cranked axles and horizontal cylinders, was contrived and introduced by Mr. Kennedy, and was first applied in the locomotive 'Liverpool,' which was started on the 22nd of July, 1830, by Mr. Edward Bury, then of Liverpool, and was employed in aiding in the construction of the Liverpool and Manchester Railway. The 'Planet,' the first engine constructed by Messrs. Stephenson on this plan, was not started until four and a half months afterwards; and a little later Mr. Hackworth set the 'Globe' engine to work on the Stockton and Darlington line. The late Mr. George Stephenson had told both Mr. Bury and Mr. Kennedy, after having seen the 'Liverpool' engine on the Liverpool and Manchester Railway, that his son, the present Mr. Robert Stephenson, had taken a fancy to the plan of the 'Liverpool' engine, and intended to make, immediately, a small engine on the same principle. Further, the late Mr. Robert Stephenson, brother to the late Mr. George Stephenson, had, as soon as he saw the 'Liverpool,' declared it was the best type for locomotives, and that all would have to come to it by-and-by. In fact, in the engineering world, the 'Liverpool' was considered a great stride in the right direction. That engine was as efficient a machine as had ever been made of that weight. It had been stated, that Mr. Brunel was the first to make wheels of more than 5 feet in diameter; now the driving wheels of the 'Liverpool' were 6 feet in diameter, and that engine often ran at the rate of 58 miles per hour, on a level part of the line, and with a load of twelve waggons. It had also been asserted, that the idea of the dome for a steam chamber on the boiler, in the case of the engines for the London and Birmingham Railway, was copied from Mr. Church's engine; but the latter was not made until seven years after the 'Liverpool,' and it could be proved, incontestably, from an old bill-head of the time,

[1] *Vide ante*, page 16.

that the dome on the 'Liverpool' was exactly similar to those on the succeeding engines made at the Clarence Foundry, Liverpool, by Messrs. Bury, Curtis, and Kennedy.

Mr. R. STEPHENSON, M.P.,—President,—remarked, that the working drawings of the 'Planet,' which was admitted to have been the type of the engines employed on the Liverpool and Manchester line, had been made, and the engine constructed under his direction, without any reference to, or knowledge of the 'Liverpool.' These facts could be fully confirmed by those who were confidentially employed upon the engine at the time. Neither was there any analogy between the two machines, for the 'Planet' had a multitubular boiler, the fire being urged by a blast-pipe, and the cylinders, which were as nearly horizontal as their position would permit, were fixed inside, or between the frames, because it was only by such an arrangement that they could be placed within the smoke-box, where it was considered desirable to fix them, in order to prevent the condensation of the steam in the cylinders, and the consequent loss of power. This had been resolved upon, from information given to Mr. R. Stephenson by the late Mr. Trevithick, who, in the course of some experiments, had built a brick flue round the cylinder, and had applied the heat of a fire directly to the metal, with very beneficial results, as regarded the economical use of steam. With the cylinders in the smoke-box, a cranked axle was indispensable, and there was not anything new in its use in locomotives, for the 'Novelty,' by Braithwaite and Ericsson, had one in 1829. Horizontal cylinders and cranked axles had also been commonly employed long previously, in Trevithick's, Gurney's, and almost all the other locomotives for turnpike roads. The statements alleged to have been made by the late Mr. George Stephenson, as to the priority of the peculiar arrangement of the 'Liverpool,' in this respect, or those asserted to have proceeded from the late Mr. Robert Stephenson, as to its being the best type for locomotives, could not therefore be admitted to be correct.

Mr. EDWARD WOODS said, he had always understood that the 'Planet' was the first of the class of engines with inside cylinders, outside bearings, and cranked axles; and up to the present time, no claim had, to his knowledge, been put in, on behalf of the 'Liverpool,' that it suggested the kind of engines which had long been designated of the 'Planet' class. In a letter he had recently received from Mr. Booth—well known from his long connection with the Liverpool and Manchester Railway—that gentleman stated, that "the 'Planet' engine was always regarded as the first of her type of engine—namely, inside cylinders and outside framing. Mr. Bury's engines, as far as my recollection will carry me back, (twenty-six years), had inside cylinders, but without out-

side framing. As to dates, I find by an old minute-book, that the arrival of the 'Planet' was reported to the Directors, at their meeting on the 4th of October 1830—and three weeks afterwards, at their meeting on the 25th October, it was reported that Mr. Bury's engine, the 'Liverpool,' was ready for trial. Substantially, these two engines appeared to be contemporaneous."

Mr. Woods added, that the 'Planet' took the first load of merchandize from Liverpool to Manchester on the 4th December 1830. He thought it probable that the 'Liverpool' might have arrived on the line at the end of July 1830, and that it was employed, in the first instance, in ballasting; but no trial of the engine took place until some weeks after the arrival of the 'Planet.' It was, therefore, evident that the designs of the two engines were totally independent of each other, and that the 'Liverpool' did not lead to any suggestions, as regarded the construction of the 'Planet,' from which it differed materially. The 'Liverpool' was a four-wheeled coupled engine, with cranked axles and cylinders under the smoke-box. The hand-gearing was placed in front of the smoke-box, where the driver stood, the stoker being in the usual position, at the other extremity of the engine, or fire-box end. The outer fire-box was domed, and contained a very small internal fire-box. The boiler was not multitubular, like that of the 'Rocket,' 'Planet,' and all subsequent locomotive engines, and which contributed essentially to the excellence of their performance, but contained a number of convoluted flues, dissimilar to the series of flues in the ordinary locomotive of the present day. The furnace was urged by a blast from a pair of bellows working under the tender, and not by the aid of the blast-pipe. This engine, after having been tried for some time, was not purchased by the Liverpool and Manchester Railway Company, probably from their not being satisfied with its performance, or construction. It was then transferred to the branch colliery line from Kenyon to Bolton, where it met with an accident, through the breaking of a wheel, and received much damage, the driver being killed. It was in consequence returned to Messrs. Bury's works, where it underwent repair, and the multitubular boilers of the 'Rocket' and 'Planet' having been found so successful, that form of construction was adapted to this engine. In this state it was again employed, and for many years remained in the service of Mr. John Hargreaves, the lessee of the Bolton and Kenyon line of Railway. In this second stage of its existence, it might be accounted as the type of the excellent class of engines for which Messrs. Bury's firm became so deservedly celebrated. In its first stage it did not represent any form of engine now in use, much less that of the 'Planet,' which had the multitubular boiler, with cranked axles, cylinders in the smoke-box, outside frames, and outside bearings.

It could not, therefore, be said to have suggested, in any way, the form of the 'Planet.'

Mr. PHIPPS said, it appeared from the delivery Journal kept at Messrs. Stephenson's manufactory at Newcastle, that the 'Planet' was charged to the Liverpool and Manchester Railway Company on the 3rd September 1830. Therefore, assuming Mr. Kennedy's statement to be correct, that the 'Liverpool' arrived in July, there would not have been sufficient time to have constructed another engine. He might state that at the time referred to, he was engaged with Mr. Robert Stephenson, at Newcastle, and could speak confidently as to every bolt and nut that was introduced into the engine. It was a subject of frequent consultation between Mr. R. Stephenson and himself, and he was sure that he should have recollected hearing of so important a fact, as that of a cranked axle having been used in any other engine. He did not recollect to have even heard of the name of the 'Liverpool' engine until this discussion arose, and it was fair to assume, that nothing was known of it at Newcastle at that time. With regard to the position of the cylinders, repeated conversations were held between Mr. Stephenson, the late Mr. Hutchinson, and himself, with respect to the saving of fuel that would be effected by placing the cylinders within the smoke-box; they also had a great desire to fix the cylinders in a horizontal position, as it was found necessary when an engine travelled at a quick speed, that the vertical motion of the springs should be eliminated from the cylinders, and this naturally led to the horizontal arrangement.

Mr. KENNEDY explained, through the SECRETARY, that the 'Liverpool,' as previously stated, was first set to work on the Liverpool and Manchester Railway, on the 22nd July, 1830. After being at work some time, the cranked axle was broken, when she was taken off the road to have it welded. The 25th of October, the date given by Mr. Booth, was that of Mr. Bury's second application to the Directors of the Liverpool and Manchester Railway, to allow his engine to be again put on the line, after her cranked axle had been repaired, and not that of the first application, which was made and granted some months before. The letter-book of the firm, for the year 1830, contained the whole correspondence on the subject, between the Directors and Mr. E. Bury.

Mr. D. K. CLARK said, that this was entirely a question of dates. But with regard to the cranked axle, he might remark, that the question of precedence was not, in his judgment, important, inasmuch as he believed the cranked axle essentially an objectionable feature in locomotives, and one which would ultimately be superseded in railway practice by the straight axle.

Since the Paper was written, he had collected a few more par-

ticulars of the working of engines, bearing upon the points of economy treated of in the Paper.

1st. As to the economy of fuel, by the correct equilibration of the engine. The 'Canute' passenger-engine, and the 'Norman' goods-engine, on the South-Western line, having been equilibrated with good results, the other engines of the same classes were likewise equilibrated. He was not in possession of results for the passenger-engines in the form proper for comparison; but, for the goods-engines, he obtained from the Company's works, the following results of working, before and after they were correctly equilibrated, up to a recent date:—

Name of Engine.	Before Equilibration.			After Equilibration.		
	Miles Run.	Average Load in Waggons.	Coke and Coal per Mile.	Miles Run.	Average Load in Waggons.	Coke and Coal per Mile.
	Miles.	Waggons.	lbs.	Miles.	Waggons.	lbs.
Norman . . .	26,888	31·2	26·1	21,319	27·5	23· 4
Saxon . . .	36,418	28·0	28·3	12,279	25·9	23· 6
Albion . . .	19,042	26·4	28·4	13,662	27·3	20· 9
Samson . . .	26,143	26·4	24·1	12,434	27·7	23· 9
Total . .	108,491	..	..	59,694	..	..
Average .	..	28·0	26·7	..	27·1	22·95

The averages of these four goods-engines, showed that before equilibration, the consumption of fuel was nearly 27 lbs. per mile, with an average train of 28 waggons; and after equilibration, 23 lbs. per mile, with an average train of 27 waggons. Allowing, say 1 lb. of fuel extra for the same number of waggons, there remained a saving of 3 lbs. per mile, or 11 per cent. This result confirmed the estimate of presumable saving already made in the Paper.

Two passenger-engines on the Cork and Bandon Railway had been equilibrated, according to the rule given in the Paper, with similar satisfactory results. On the same class of trains, the consumption of fuel before and after equilibration, was stated to be at the rates of 26 lbs. and 22 lbs. per mile, and there were 8 and 10 carriages in the train, respectively; showing a saving of at least 15 per cent. of fuel.

Respecting the economy by heating the feed-water, he had found, on referring to the records of American practice, that at least 25 per cent. of fuel was saved by the use of heated feed-water; confirming his deductions of the advantage resulting from the system.

He further remarked, that Messrs. Randolph, Elder, and Co., of Glasgow, had become, by experience, so convinced of the saving to

be effected by the use of hot feed-water and dry steam, in marine engines, that they had constructed for the 'Valparaiso,' Royal mail packet, a pair of double cylinder expansive engines, of 320 HP., in which the feed-water was heated, and the steam was kept dry.

On the question of the relative cost of coke and coal as fuel for locomotives, he had obtained from twenty-two locomotive Superintendents, in different parts of the country, returns of the cost of fuel used by them; and he found that the average cost of coke was, in June 1856, 18*s.* 2*d.* per ton, and of coal, 8*s.* 7*d.* per ton: showing that coal cost less than half the price of coke, whilst in estimating the saving to be effected by substituting coal for coke universally, he had only assumed a reduction of one-third in the cost of fuel.

Mr. E. Woods said, that the experiments referred to by the Author, as having been made on the London and North-Western Railway, to ascertain the comparative mechanical values of coal and coke, were made with a particular kind of fuel,—the Hawksbury Main coal, from a colliery near to Coventry. On analysis it was found, that this coal contained 67 per cent. of carbon, and 5 per cent. of hydrogen, equal to 72 per cent. of combustible matter, whilst the coke contained from 94 to 96 per cent. of carbon. In all cases where coal was brought into comparison with coke, it was important that the chemical analyses should be known, in order that the heating powers of each might be noted. He believed the statement was correct that, in these trials, 1 lb. of coke evaporated 8·65 lbs. of water, whilst 1 lb. of coal only evaporated 5·83 lbs. of water. If worked out, the evaporative powers would be found to be nearly in proportion to the amount of carbon which each contained.

The experiments on the South-Western Railway were, he believed, conducted with a superior quality of semi-bituminous Welsh coal. The fact of 1 lb. of that coal evaporating 9 lbs. of water, showed that it must have been of a very superior quality. He had travelled upon some of the improved engines on the South-Western Railway, and though he had not, in all cases, had an opportunity of weighing the fuel used, yet he was impressed with the opinion that they worked with economy of fuel and water, and the smoke was effectually consumed. He was not at present prepared to agree fully with all the claims to economy which Mr. Clark had advanced; but still he was of opinion that there was room for greater economy in the consumption of fuel and in the cost of repairs.

Mr. Frederick Braithwaite said, judging from the title of the Paper, he was not prepared for the turn which the discussion had taken, inasmuch as it did not apply so much to the improvement of the locomotive, as to the reduction of the working ex-

penses of the locomotive department of a railway. He had heard, with satisfaction, that there was a probability of coke being superseded by the use of coal in locomotives. He believed it would be generally found, that it required 5 tons of coal on the average to produce 3 tons of coke. The great peculiarity of Mr. Beattie's engine was, that the coal coked itself in the process of combustion in the fire-box, so that the great loss of heat occasioned in the manufacture of coke was saved—a waste equal to from 1 to 2 tons of coal, on the calculation that it required 5 tons of coal to produce 3 tons of coke; and if such were the facts, a great economy would be effected, tending to reduce the locomotive expenses, especially if it was true that 1 lb. of coal would, in practice, evaporate 9 lbs. of water. When, however, they were told of other savings of 30 per cent. in one direction, and 20 per cent. in another, he confessed that he was taken by surprise.

Mr. BEATTIE said, that he had extracted from the books of the locomotive department of the London and South-Western Railway, the data from which the following statement was drawn up, showing the consumption of fuel and average loads of five engines burning coke, and five burning coal, to and fro on the main line between London and Southampton:—

Coke-burning Engines.			Coal-burning Engines.		
Name of Engine.	Lbs. of Coke per Mile.	Average No. of Vehicles per Train.	Name of Engine.	Lbs. of Coal per Mile.	Average No. of Vehicles per Train.
Hecla	19·7	9·7	Ironsides . . .	21·2	14·9
Stour	20·6	10·6	Canute . . .	17·7	12·6
Vulcan	20·8	10·2	Harold. . . .	17·6	10·4
Trent	21·4	10·7	Conqueror. . .	19·0	11·0
Frome	20·9	10·7	Crescent . . .	19·1	12·2
Average . .	20·68	10·38	Average . .	18·92	12·22

From this it appeared, that the consumption of coal per mile had been 8½ per cent. less than coke, whilst the number of vehicles per train was 14¾ per cent. greater. At the same time, the piloting of the coke-burning engines averaged 220 miles per half-year, whilst that of the coal-burning engines had averaged only 60 miles. The average cost of the coke had been 27*s.* 6*d.* per ton, and this calculated on 20·68 lbs. gave 3·04*d.* per mile. The coal (Welsh inland) had cost 18*s.* 6*d.* per ton, giving 1·87*d.* as the cost per mile of 18·92 lbs., or a saving in favour of coal-burning engines of 1·17*d.* per mile, equal to 38 per cent., with trains 14¾ per cent. heavier than those drawn by the coke-burning engines. If the loads had been equal, that is, if the coke-burning engines had

drawn trains of the same weight as the coal-burning engines, the consumption of fuel would have been at the rate of nearly 24 lbs. per mile instead of 20·7 lbs., and the cost per mile would have been 3·5*d.*, showing a saving of 46½ per cent. in favour of the coal-burning engines, without taking into account the extra assistance rendered by piloting to the coke-burning engines. Of this economy, as it took 1½ ton of the best coal to produce 1 ton of coke, he thought about 33 per cent. was due to the use of coal in place of coke, and about 13½ per cent. must be attributed to the application of the hot feed-water.

He might here remark, that he thought great economy resulted from the use of the fire-tiles; and that without them the engines would not consume their own smoke. In consequence of the fire-tiles becoming greatly heated, the smoke evolved from the coals was consumed; in point of fact the engine was making its own coke during its transit, and at the same time getting the benefit of the combustion of the gases evolved, which were for the most part wasted in the manufacture of coke. The advantage in this respect was much felt in the performance of an engine towards the end of a journey; as under those circumstances it would run home with very little fuel in the fire-box,—the heat from the fire-tiles being alone almost sufficient to keep up the pressure of steam. Recently a coal-burning engine, using only small coal, or slack, had brought a train, consisting of twenty-four carriages, from Woking to London, a distance of 25 miles, in 37 minutes, being at the rate of above 40 miles per hour, and when it reached the Waterloo Station, there was only a small quantity of fire in the box; still the steam was at a pressure of 110 lbs., and it had not been at less than an average of 120 lbs. during the whole journey. He ventured to say, that no coke-burning engine would have brought in that train, at the same velocity, with so little fuel in the fire-box. He should be happy to repeat those experiments, with any one who desired to test the working of coal-burning engines. He had not tried coke in the same engines, because he was quite satisfied with the results of the coal-burning.

A few months back the Belgian Government sent over to this country M. Belpaire, one of their engineers, for the purpose of examining into the merits of the coal-burning engines. In his Report to the Minister of Public Works, at Brussels, that gentleman had stated that the flame in the fire-box was white, and the combustion was perfect. There was no smoke, even whilst firing and stoking. If, during the stoppages after firing, the gases from the chimney were faintly tinged with colour, a slight jet of steam discharged up the chimney rendered them colourless again. The steam-generating power of the boiler was also admitted to be undoubted. In a trial with the 'Canute,' coal-burning passenger-

engine, M. Belpaire found, that from London to Southampton an average speed of 0·635 of a mile per minute was maintained, when exerting a tractive force equal to drawing 760 carriages a mile. On the return journey from Southampton to London, the average speed was 0·492 of a mile per minute, and the tractive force was equal to drawing 1,146 carriages a mile. The consumption of fuel was 19·15 lbs. per mile, including the quantity used in lighting the fire.

Mr. CRAMPTON said, that for the last two years they had been burning coal, pressed together with a little tar, on the Great Northern of France Railway. Twenty of his express engines were running daily, burning only coal: and altogether there were two hundred coal-burning engines on that line, and at least four hundred in France. The result had been a saving of one-third in the cost of fuel. On the Great Northern of France line the coal used was very good, and there was very little smoke from it. The only means adopted for the consumption of the smoke was a step-grate, which was merely a horizontal arrangement of the fire-bars, placing them transversely, and in steps across the fire-box, so as to have wide air-spaces, without the risk of losing the fuel through the spaces. By care in firing, they got such a mass of flame, that with a copious admission of air, the smoke was perfectly consumed. When, however, very bituminous coal was tried, the experiment was a failure.

In the consideration of this subject the quality of the fuel formed an important element, in determining the quantity of water which a pound of coke, and the same quantity of coal, would respectively evaporate. He did not think that the comparative evaporative efficiency of coal and coke could be fairly arrived at, by contrasting the results of Mr. Beattie's coal-burning engines with coke burnt in other engines; because Mr. Beattie had an ingenious method of heating the feed-water by means of the waste steam, which, there was little doubt, induced an economy of 15 per cent. It would have been more conclusive to have tried coal and coke in the same engine alternately. He mentioned this, in order that they might not be led away by false ideas of saving.

Mr. D. K. CLARK said, that he had burned coal and coke, alternately, in the same engine, the 'Canute.' In one of his experiments the consumption of coal was 915 lbs. per hour—the area of the fire grate being 16 square feet. In this case 9⅓ lbs. of water were evaporated by each 1 lb. of coal, whilst in the same engine only 7⅓ lbs. of water were evaporated by each 1 lb. of coke.

Mr. BEATTIE, in reply to questions from different Members, said, he had recently got up steam with 4 cwt. of Griff, which was a hard coal, and had afterwards used on the journey to Southampton and back, 21 cwt. of coking coal, which was highly

bituminous, and both were consumed with the same satisfactory results. The first cost of the boilers of the South Western coal-burning engines would be little more than that of ordinary boilers, and there did not, at present, after very heavy running, appear to be any evidence of more rapid destruction of tubes, or of fire-boxes, than when burning coke. Indeed there was reason to apprehend, that the particles of coal in combustion would do less mechanical injury to the tubes, than the bits of hard coke rapidly travelling through. Thin and careful firing was recommended by engineers who had tried to consume coal in locomotives, but in the arrangement of boiler he had described, this was not necessary, the firing being less frequent to maintain high-pressure steam, than with the engines burning coke. There could not be a doubt but that the locomotive boiler could be made to consume coal, with as good a result as the stationary boiler, under which coke was never considered necessary. He could not give any precise information as to the expense of repairs, as so few had as yet been required. The fire-bricks lasted as long as in coke ovens. Some of the engines had run from 28,000 to 30,000 miles during the present year.

Mr. CRAMPTON remarked, that the capability of burning both coking and hard coal equally well was an important fact. He had not seen any apparatus that would thoroughly consume the gases, and at the same time get up steam. In his own case, if he ran an express train with strong coal, there was much smoke; but with the Belgian coal, which was a dry coal, very similar to the Welsh, this was not the case. He had no desire to disparage the system advocated by Mr. Beattie, who, he thought, was entitled to great credit for what he had done. Still, as a practical man, he must confess that he doubted whether that gentleman's particular form of engine would be the one generally adopted for burning coal in locomotives. It appeared to him that the boiler was too complicated, and that, in practice, there would be some difficulty in properly arranging and adjusting the fire-tiles. Under Mr. Beattie's own eye the system might perhaps be made to answer, but when consigned to the care of ordinary workmen, he doubted whether the results would be so satisfactory.

Mr. H. ROBERTSON was convinced, that the use of coal, in place of coke, on railways, would result in a large saving in the expenses of the locomotive department. The chief difficulty to be overcome was to get rid of the nuisance of smoke. From experience he could say, that this had been successfully accomplished in the South Western coal-burning engines, and also on the Shrewsbury and Hereford Railway, where coal only had been used during the last six months. Mr. Brassey, who was the lessee of the latter line,

had encouraged Mr. Jeffrey, the locomotive superintendent, to persevere in overcoming this difficulty, and he had done so completely. The plan adopted by Mr. Jeffrey was to fit each engine with a moveable frame for the fire-bars, which were thin and flat, had a space of 1¼ inch between them, and were placed longitudinally in the fire-box. There was thus plenty of room for the admission of air, and little liability to clinker. By the use of the rocking frame, the level of the bars could be varied at pleasure, according to the condition of the fire and the work to be performed. At the end of a trip, the fire could be dropped out without disturbing the bars, saving not only the fuel, but the bars, and the labour attendant on the old mode of dropping the fire; and by lifting one side of the frame any clinker could be removed. By this contrivance, an engine having run from Shrewsbury to Hereford, could be taken over the pit, drop her fire, have the whole of the clinker removed, and be ready to start with a clean fire in about a quarter of an hour. There was no difficulty in getting up the steam.

Mr. Jeffrey had furnished him with the following results of burning all coal in the six passenger- and eight goods-engines on the Shrewsbury and Hereford Railway. The average price of coke was taken at 20*s*. per ton, and of coal at 11*s*. per ton at the terminal stations.

PASSENGER-ENGINES.

	Miles Run.	Coke.		Coal.		Coke per Mile.		Coal per Mile.		Total Fuel per Mile.	
		Tons.	Cwt.	Tons.	Cwt.	Lbs.	Value	Lbs.	Value	Lbs.	Value
							d.		*d.*		*d.*
Burning Coke and Coal.	360,632	1660	10	1757	12	10·31	1·10	10·92	0·64	21·23	1·74
Burning Coal only	81,969	..	..	693	3½	..	..	18·94	1·12	18·94	1·12
Saving per Mile										2·29	0·62

The above statement showed a saving of 0·62 of a penny per mile on the cost of fuel by burning all coal, compared with burning half coal and half coke. These engines, when burning only coke, could never be got below 18½ lbs. per mile, whereas they now only burned 18·94 lbs. of coal, taking the same average load of six carriages, and running at the same speed in all cases. This gave a saving of about 50 per cent. in value in favour of all coal as compared with all coke.

FOUR-WHEELED GOODS-ENGINES.

	Miles Run.	Coke.		Coal.		Coke per Mile.		Coal per Mile.		Total Fuel per Mile.	
		Tons.	Cwt.	Tons.	Cwt.	Lbs.	Value	Lbs.	Value	Lbs.	Value
							d.		*d.*		*d.*
Burning Coal and Coke . . .	189,593	2782	2	1422	9	32·87	3·51	16·81	0·99	49·68	4·50
Burning Coal only	39,193	..	..	719	19	..	..	41·14	2·42	41·14	2·42
Saving per Mile										8·54	2·08

The foregoing statement showed a saving of 2·08 pence per mile on the cost of fuel by burning all coal, compared with burning one-third coal and two-thirds coke. The average load was 168 tons, including waggons, in both cases.

SIX-WHEELED GOODS-ENGINE.

	Miles Run.	Coke.		Coal.		Coke per Mile.		Coal per Mile.		Total Fuel per Mile.	
		Tons.	Cwt	Tons.	Cwt	Lbs.	Value	Lbs.	Value	Lbs.	Value
							d.		*d.*		*d.*
Burning Coke and Coal. . . .	72,473	1232	8	613	4	38·09	4·07	18·95	1·12	57·04	5·19
Burning Coal only .	47,550	..	..	917	4	..	..	43·20	2 54	43·20	2·54
Saving per Mile										13·84	2·65

This statement showed a saving of 2·65 pence per mile on the cost of fuel by burning all coal, compared with burning one-third coal and two-thirds coke. The average load was 188 tons, including waggons, in both cases.

These facts were valuable, as being commercial results from the regular working of the whole traffic of the Company, with the same engines, doing the same work, on the same line of railway; the conditions being all alike, except that, in one case, all coal was used instead of a mixture of coke and coal. These returns gave the whole quantity of coal used in the department, including the workshops, and the coal used for lighting the fires. He did not think a more successful result could be expected from engines constructed for burning coke, and he looked forward to improved results from engines specially constructed for burning coal, like the 'Canute' of Mr. Beattie. The great difficulty was in avoiding

the emission of smoke; but, by having a jet of steam in the funnel, to produce a draught when the engine was waiting at stations, and getting the men into a proper system of firing, there was no fear of complaint on that score. He had seen coal-burning engines come into the Shrewsbury general station emitting less vapour than was sometimes the case with the coke-burning engines. With respect to the question of the repairs of the tubes, he would add, that Mr. Jeffrey had found the cost less, when burning coal than with coke, as the tubes were comparatively free from the fine particles of coke, which were carried through by the sharp draught, and which "furred" up and cut the tubes. This "furring" up of the tubes required a frequent use of the cleaning rod, which was not the case with the coal-burning engines.

Mr. A. SLATE remarked, that the use of coal, instead of coke, in engines, resolved itself into the question of the combustion of the carbon evolved from the fuel in the first instance. When more carbon was mechanically disengaged from the mass, than was chemically combined with the gases, visible smoke was formed. He had no doubt that the same thing occurred, to some extent, in the combustion of coke, although the gaseous vapour might not be visible. Heat was an important element in the proper combustion of the gases. The reason why carbon escaped, in the shape of smoke, in an engine burning coal, was that there was not a due supply of oxygen; whereas in Mr. Beattie's engine, the element of heat was, to some extent, supplied, by the heated fire-bricks. On an average these bricks would be raised to a higher temperature than the gases, and they would give out the heat necessary for combustion. It appeared to him that, in all locomotive engines, there was an inadequate supply of oxygen. If a due amount of air, at a high temperature, could be injected into and be mingled with the gases evolved, they might obtain an amount of heat similar to that produced by the blowpipe.

Mr. EXALL thought the object was not so much to get rid of the nuisance of smoke, as to obtain the greatest quantity of heat from the coal, as the nuisance was generally least when the economy was greatest. When the fire was even and thin upon the bars, smoke was avoided; but if the mass of fuel was thick, smoke was evolved, as the passage of the air through the mass was prevented, and consequently there was imperfect combustion. His experience with portable engines had been chiefly confined to those of a small class, generally having about 4 to 6 square feet of fire-grate, and a light blast. In these he had found that the best fire was about 3 inches thick on the bars, or 2 inches if the coal was very fine, and sometimes even as little as 1 inch. The finer the coal, the thinner should be the fuel upon the bars. He preferred thin bars, only sufficiently thick to prevent warping, and getting out of shape.

Care must be taken to keep the bars always properly covered. The great thing, however, was the proper admission of air through the coal; as much mischief might be done by letting in air which was not necessary for combustion, as by keeping it out. He believed that, with proper care, almost any kind of coal might be burnt with advantage.

Mr. T. WEBSTER could bear his testimony to the freedom from smoke of the engines on the South-Western Railway, under Mr. Beattie's system. An alarm was at one time felt, with regard to the distance the sparks would fly, at a heat dangerous to contiguous property, but he thought that question was now set at rest. Referring back to the Minutes of the Institution, he found that in 1839,[1] Mr. C. W. Williams read a Paper "On the Properties and Composition of Peat and Resin Fuel," in which various instances were quoted of the great additional amount of heat obtained from coke, as compared with a like quantity of coal; and tested in that manner, no doubt such a result would follow. The coke, however, was produced in the most perfect state for use, at an expenditure of heat in another place. In the course of that discussion, it was stated by Mr. Lowe[2] that, "to say that the 15 cwt. of coke, produced from a ton of coal, was equal in heating powers to the original ton, was to say that there were no heating powers to be derived from the 9,000 or 10,000 cubic feet of gas produced, or the 10 gallons of tar." As regarded Mr. Beattie's engine, the practical point was, whether he had not discovered the means by which he could so combine the gases as to utilize them in the combustion of the coal? It might be matter for consideration, whether it would be more economical to drive off a certain amount of hydrogen, ordinarily found in coals, and other gases which either produced water, or were incombustible; but if no advantage was to be derived from that, then the great desideratum must be, so to construct the furnace, either of the locomotive, or of fixed engines, as to be able to utilize all the gases evolved. Another discussion on the same subject took place in 1840, on a Paper by Mr. Charles Hood, "On the Properties and Chemical Constitution of Coal,"[3] when Mr. Parkes gave the results of some recent experiments by Mr. A. M. Perkins, as to the destruction, on the same grate, of equal weights of coal and coke, when it was found that coke effected a greater evaporation than coal, at similarly rapid and slow rates of combustion. That was what might have been expected, when there was no economical application of the gases evolved from the coal.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1839), p. 38.
[2] Ibid., p. 41.
[3] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1840), p. 62.

Mr. G. P. BIDDER, V.P., said, they were much indebted to Mr. Clark for having brought this subject before the Institution, because a saving, however small, in any department of the working of a railway, taking into account the enormous extent of the system, was a matter of great importance. Although the question had been treated with great ability by Mr. Clark, and the documentary evidence brought forward during the discussion was very conclusive, there were needed many more facts of an accurate description, to enable a sound conclusion to be arrived at. The discrepancy in the evaporative powers of coal and coke must be explained, as otherwise no useful result whatever could be obtained. The relative prices of coal, and its character in different localities, must also be known, and in the case of export to places where no coal was found, the relative condition in which coal and coke would arrive at their destination, must be taken into consideration. At this moment, in India, it would be important to burn only coal, as indeed had been done on the East Indian Railway for some time, and therefore, it was desirable to ascertain, as clearly as possible, which were the best methods for effecting this object.

He travelled constantly upon the South-Western Railway, and could bear testimony to the remarks which had been made, as to the general absence of smoke. He had no doubt that the use of coal, in certain situations, would result in considerable saving; and he believed that Mr. Beattie's system deserved great attention, and that it might be applied in many instances with advantage.

With regard to the equilibration of engines, which had been too little touched upon in the discussion, that was a subject which had for a long time occupied the attention of locomotive superintendents, particularly of Mr. J. V. Gooch, on the Eastern Counties Railway. The express trains on that line ran from London to Norwich and Yarmouth, at a speed of about 38 miles an hour, including stoppages. These trains were heavy, and yet the consumption of fuel, including getting up the steam, was only 18 lbs. of coke per train per mile. This result Mr. Gooch attributed, in a great measure, to the balancing of the engines, which not only induced economy in the consumption of fuel, but what was of more importance, reduced the wear and tear of the carriages, and increased the safety of the running of the trains.

He hoped that on a future occasion the subject would be again discussed, when the experiments would be more precise than anything that had been laid before that meeting; because the condition of the engines—the amount of care in working them—and even the state of the wind—would occasion discrepancies, which, if not noticed, would lead to very erroneous conclusions.

Mr. CRAMPTON, through the SECRETARY, stated, that he coincided with Mr. Clark's views respecting the unsteadiness of ordinary

locomotives, and attached importance to balancing the working parts. But as it appeared to be considered, that Mr. Crampton's locomotives obtained superior steadiness, only at the expense of increased wear and tear of the tyres of the leading wheels, he hoped that a few remarks would not be thought inappropriate.

Some time before the gauge controversy, and whilst engaged on the Great Western Railway, Mr. Crampton's attention was first drawn to the necessity of giving increased steadiness to the engine; and he addressed a letter to the Editor of the 'Railway Times,' in 1843,[1] in which he expressed the opinion, that one of the causes of unsteadiness, was owing to the piston, piston rod, and connecting rod, being unbalanced, and that this unsteadiness did not result from the action of the steam, as had been supposed. This he believed to be the first published statement upon the subject. In the first engine which he constructed, all the reciprocating parts were weighed, and two-thirds of their weight were applied to balancing. In this particular case it was not necessary to use the whole weight for that purpose, inasmuch as there was only a trifling weight upon the centre wheels. Mr. Bodmer's plan was the only one that he knew of, which effected a perfect balance, but that was too complicated. Monsieur Nollau, in 1848, and Monsieur Le Chatelier, in 1849, investigated the subject theoretically, and it might be said, that it had been practised on the Continent as a principle, before English Engineers as a body admitted its value.

It did not appear that the conclusions to which Mr. Crampton had arrived respecting the requirements of locomotives were fully appreciated by Mr. Clark. These were, never to use a cranked axle, as straight axles were simpler, and engines having them could easily be made to run steadily; to place every portion of the machinery, including the eccentrics, regulators, &c., completely on the outside; to lower the centre of gravity; and to have the greatest weight upon the extreme wheels. All these points had been carried out, and appeared to have been generally appreciated, since fourteen out of the twenty-two locomotive engines exhibited at the French Exhibition embodied, in one form or another, parts of this system; and there were at present upwards of six hundred engines at work constructed upon this principle.

With regard to the weights on the wheels, he might state, that in fifty engines of one class, the total weight being 27 tons, 11 tons were placed on the driving wheels, 7 tons on the centre wheels, and 9 tons on the front wheels. In his opinion, 11 tons was the maximum load which should be put upon the driving wheels. The

[1] *Vide* 'Railway Times,' vol. vi. (1843), p. 135.

weight on the leading wheels was about the same as was usually placed upon those of ordinary engines of a total weight of 27 tons. It was not necessary that, for the same power, there should be a greater distance between the extreme wheels, inasmuch as the total length of the engine could be reduced, if required, by adopting a larger boiler with shorter tubes. All practical men knew, that his system did not involve any additional weight for a given power, under similar circumstances. No correct results could be arrived at, by comparing one of Mr. Bury's engines of 20½ tons weight, with one of his engines of 27 tons weight. It was no doubt possible to find a few engines of very early construction on his principle, which might contain several objectionable points; this was incidental to all novelties; but when a system was criticised, it was illusory to select, as examples, the results of first efforts, but rather its later developments.

With regard to the asserted increased wear and tear of his engine, he had been furnished with a statement by the Engineer of the Northern Railway of France, which showed that the cost of repairs of all the engines on his plan, from 1849 to the end of November 1856 (nearly eight years), was sixteen and a half per cent. less than that of other engines on that line, during the same time. The total distance run had been 4,010,607 miles; and the average distance run yearly by each engine, during the whole of that period, was 25,428 miles. This was the more remarkable, when it was considered, that the distance between the extreme wheels was 2 feet 6 inches more, the distance run by each engine one-third more, and the speed attained one-third greater, than was the case with the other engines. The Engineer attributed these results to the facility with which every part could be inspected and kept in repair, and also to the increased steadiness of the engine. Although these results were more favourable than Mr. Crampton could have anticipated, yet he felt convinced, that in all cases in which engines were equally well constructed, those offering the greatest facilities for inspection and repairs, and which ran the steadiest, must show an advantage, both as regarded cost of maintenance, as well as in the number of miles run in a given time.

Mr. D. K. CLARK observed, in reply to Mr. Crampton's remarks, communicated through the SECRETARY, that the first public assertion of the principle of complete equilibration of locomotives in this country, was made by Mr. Bodmer, in 1841, when he patented his mode of making a perfect balance. If Mr. Crampton balanced two-thirds of the reciprocating weight, in the first engine he constructed, it was remarkable, that he ceased to do so, in the engines he subsequently made, on his principle. Mr. Crampton's conclusions as to the requirements of locomotives,

were not, as a system, appreciated in this country; after various trials, that system had been abandoned, and only in France had it been extensively adopted. Practical men did not all agree, that that system involved no additional weight for a given power. This assertion was only true of the system, with respect to the particular element of boiler-power; whereas, boiler-power was of no particular advantage, and was a real disadvantage, in so far as it involved superfluous dead weight, unless the two other elements, cylinder-power, and adhesion-power, were proportioned to it. The adhesion-power was, in reality, the practical limit; now, Mr. Crampton had acknowledged that 11 tons was the maximum driving load that should be placed on a pair of driving-wheels, and the experience of engineers would confirm the assertion that there were steady-running engines, weighing 21 tons, like Mr. Bury's, with single wheels, containing ample power of boiler and cylinders, for 11 tons driving weight. It followed, that the gross weight of Mr. Crampton's 27 tons engine, with the same driving weight, 11 tons, was 6 tons more than the weight which was usefully available, for purposes of adhesion, or was necessary for stability. Mr. D. K. Clark, so far from selecting, for comparison, the results of the first efforts of Mr. Crampton, had selected the class of engine made by MM. Dérosne and Cail, Paris, for the Chemin de Fer du Nord (No. 122), and which Mr. Crampton had said, embodied a fair representation of his system. If a reference might be permitted to the 'Liverpool,' on that system, made for the London and North Western Railway, and which weighed 35 tons gross, it might be mentioned that, with 12 tons on the driving wheels, there were 17 tons on the leading wheels, or nearly one-half more,—showing the comparative scarcity of weight, on this system, where most was required. The statement of the performance of these engines in France was of no value in this discussion, without an accompanying detail of the various classes of engines alluded to. The expedient suggested for reducing the length of the wheel-vase, to that of the ordinary system, by enlarging the boiler and shortening the tubes, was of very limited practical use; it had been worked out to an injurious excess, on one of the principal lines in this country, as had been demonstrated by the results of practice; and, further, the same expedient was applicable to all systems.

Mr. W. Bridges Adams, through the Secretary, said, that as the process of coking diminished the total weight of the coal 25, or more, per cent., while the cost per ton was nearly doubled as compared with coal, it was natural that locomotive superintendents should desire to substitute, if possible, coal for coke. But both coal and coke were of varying qualities. Coal was commonly divisible into coking, or bituminous, and anthracite, or non-bitu-

minous. There were objections to both kinds. The bituminous coal melted into a mass, and the anthracite decrepitated under heat, so that in both cases the free passage of atmospheric air amongst the particles of the burning fuel, which was essential to combustion, was impeded. Coke, by its peculiar chemical and mechanical structure, required less air than bituminous coal, and provided freer passage between the lumps. To burn coal, therefore, required a large grate area, with reduced depth of fuel; whilst to burn coke, a small grate area, with a considerable depth of fuel, would suffice. In burning bituminous coal in a locomotive fire-box, a distillation of the coal into gases took place, which gases could not be burnt without a large supply of air and heat in direct contact. As heat was abstracted by water-lined surfaces, it was essential to resort to some substance serving as a heat accumulator. This had been accomplished by Mr. Beattie, with the perforated brick diaphragm, in which the principle of the heated bridge of stationary smoke-consuming furnaces was judiciously applied. With regard to burning coal in existing locomotives, there was an experiment worth trying. Some years back, there was an article used in ordinary domestic fires, called a fire-ball. It was a sphere of fire-clay, about 4 inches in diameter, and pierced through in several directions, intersecting the centre, by holes $\frac{1}{2}$ an inch to $\frac{3}{4}$ of an inch in diameter. Several of these balls were placed in the bottom of the grate, on the ordinary bars. They got red hot, and kept up a supply of heated air to the burning fuel mixed with them. He thought it would be worth while to place a layer, or two, of these balls, on the bars of a locomotive, to try the experiment of burning coal, with their aid. Wood-burning engines required constant feeding, and were exceedingly wasteful. He had been informed that locomotives burning anthracite, were now used in the United States, and that the fire-boxes were much larger than those of the wood burners.

It must not be forgotten, that one considerable advantage in the use of coke was, getting rid, more or less, of the sulphur, which was very mischievous in its consumption to iron, copper, and brass. Therefore, if raw coal were used, it would be important to select the quality containing the least amount of sulphur. The experiment might be made, of lining the whole of the fire-box and the fronts of the tubes and roof with fire-bricks, and covering the bars with fire-balls, in order to ascertain if very sulphurous coal could be burnt without injury to the metal. It would also be desirable to try, if artificial fuel could be prepared, of a denser body than coke. It was obvious, that every time the door was opened to feed the fire, the temperature was lowered, by the rush of cold air through the tubes; and if, by condensing the fuel to as high a point as possible, the fire-box could be charged for a whole trip,

this disadvantage might be avoided. Possibly, anthracite coal, crushed, to destroy its crystalline texture and friability, and then recombined, might answer well. He suggested whether economy might not result from the use of distilled water in the boilers, so as to avoid incrustation, and the necessity for blowing off. It would be better to consume a certain amount of fuel in providing pure water, than to consume fire-box and tubes and extra fuel in producing steam from foul water, and at the same time lowering the power of the locomotive. It would be a great advantage, not to cool the boiler surfaces suddenly, and thus avoid leakage, the tendency to rust after evaporation, and saving time in the morning in getting up the steam.

Mr. BEATTIE remarked, through the SECRETARY, that as so much interest had been manifested in the particular form of coal-burning engine which he had brought out, he should have great pleasure in presenting to the Institution an engraving of the 'Canute,' referred to by Mr. D. K. Clark, for publication in the Minutes of Proceedings (Plate 1). The most precise description of this engine was that given in the specification of his patent, from which the following portion was extracted:—

"Fig. 1 is a side elevation of the engine and part of the tender, showing the condenser **K** in front of the chimney, with the overflow pipe, **11**, which carries the hot water back to the tender, through the pipes **S** and **T**.

"Fig. 2 is a longitudinal section, showing the boiler **I**, combustion chamber **F**, and furnaces **A** and **C**; also the internal arrangements of the heating apparatus, on the inside and the outside of the smoke-box, together with the disposition of the pumps.

"Fig. 3 is a transverse section of the combustion chamber, through the centre of the manhole **G**, showing the arrangement of the fire-tiles.

"Fig. 4 is a transverse section through the smoke-box and heating apparatus, showing the connection of the steam-cylinders and exhaust-pipes, and the heating and condensing apparatus.

"Figs. 2 and 3 show the construction of the furnaces and boiler, wherein the crude coal and the gases generated therefrom are consumed. **A** and **C** are two furnaces separated from each other by the inclined water-space partition **B**, which is perforated by rows of tubes. A transverse hanging bridge **D** is attached to the roof of the fire-box.

"The apertures **A'** and **C'**, for supplying the coal to the furnaces, are formed by hollow water-space rings, which are riveted to the outer and inner fire-boxes. The combustion chamber **F** is complete and independent in itself, and is permanently fixed in the boiler, by means of the manhole **G**, and the stays which pass through the water-space division; and the ring is supported by

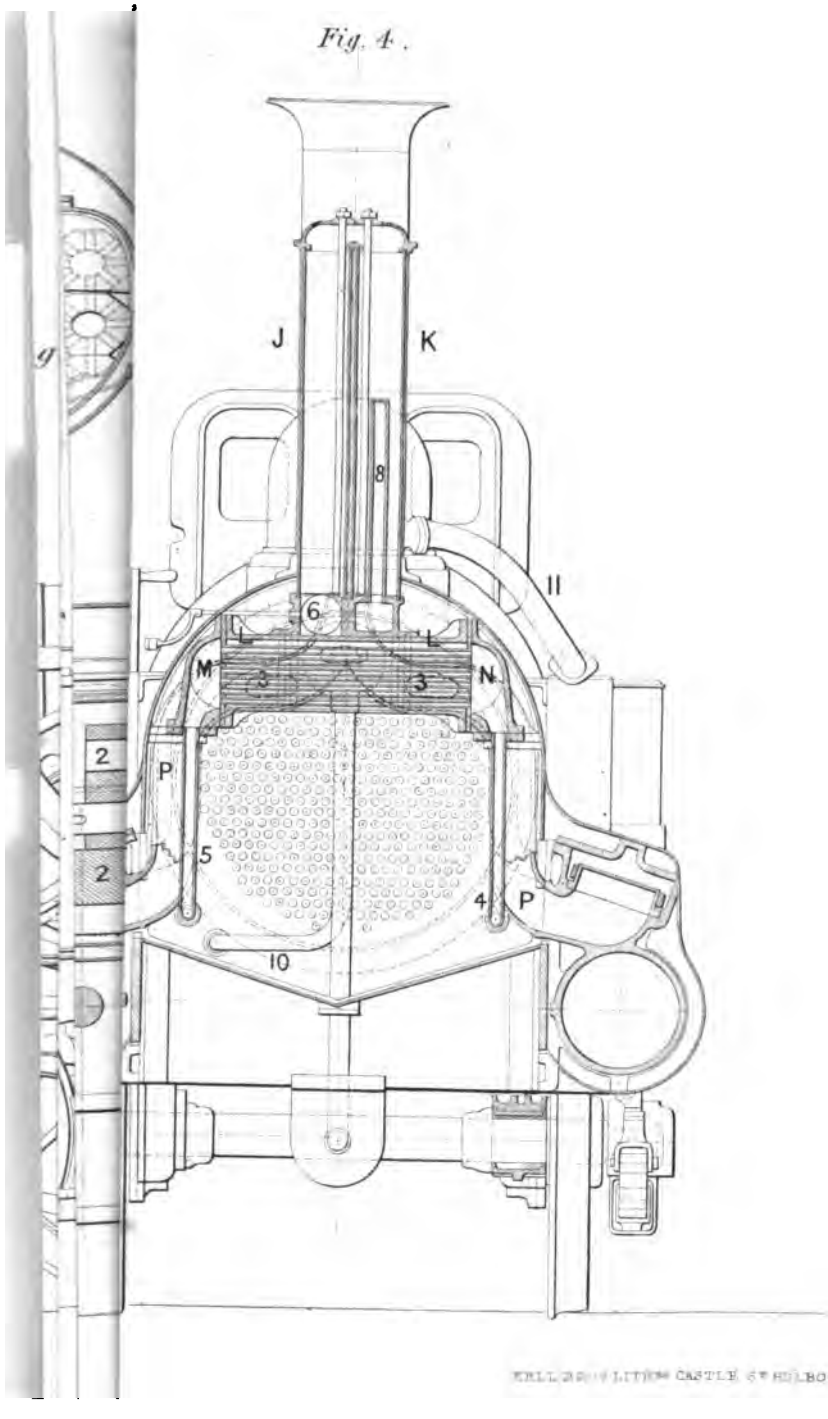
the transverse hanging bridge F'. The connection between the furnaces and the combustion chamber is formed by the hollow water-space ring E, which is riveted to the fire-box and bolted to the combustion chamber; by which means, when the fire-box is worn out, or requires repair, it can be taken out, without the necessity of disturbing the combustion chamber, or the tubes I I, in the boiler.

"The first set of fire-tiles, 1, 1, are placed across the narrowed outlet, or throat of the furnace, A, and leave intervening spaces between, for the passage of the flames and gases generated in the furnace. The second set of fire-tiles, 2, 2, are octagonal and tubular, and are placed in the combustion chamber, thereby allowing the flame and gases to pass through and around them. The coals being ignited in the furnace A, the gases generated therefrom are raised to a high temperature, whilst passing between the heated fire-tiles, and are prepared for flaming; they are then deflected downwards, by the hanging bridge D, over the fire in the furnace C, being mixed with the flames and gases emanating therefrom, and all pass through the fire-tiles situated in the combustion chamber. The furnaces A and C are furnished with separate and distinct ash-pans and dampers, so that the combustion of the gases can be adjusted most accurately, by the admission of air to either furnace.

"The apparatus for heating the feed-water consists of an outer condenser, formed of two upright pipes, J, K (Fig. 4), placed in front of the chimney, and of an inner tubular chamber, L L (Figs. 2 and 4), placed inside the smoke-box. The pipe J communicates at the bottom with the exhaust steam in the lower chamber L L, and is provided with a throttle-valve 6, to regulate the admission of steam. The other pipe K, or condenser proper, communicates with and receives its steam from the pipe J, by means of the cap 7 at the top; it is further furnished with an injection-pipe 8, which is perforated near the top, and is connected to the cold-water pump at the bottom, by means of the pipe 10. The tubular chamber L L is constantly filled with steam from the exhaust pipes P P, whereby the tubes 3 3 are highly heated. The chamber L L is surmounted at each end by hollow caps, M N, for the ingress and egress of the water, which is delivered into the apparatus from the hot-water pump O (Fig. 2), through the pipe 4 (Fig. 4), and then passes out by the pipe 5 into the boiler. The overflow-pipe 11 conveys the hot water from the condenser, which, passing through the outer coupling-pipe S, and inner inclined tube T, is delivered into the tender. The overflow-pipe 11 is furnished with a branch pipe 12 (Fig. 1), and a cock with handle 13, which communicates with the feed-pipe 14, and the hot-water pump.

"The action of the combined heating apparatus is as follows:—

Fig. 4.



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The cold water from the tender is constantly being forced, by the cold-water pump, through the injection-pipe 8, into the steam contained in the condenser K; the heated water generated by such process falls to the bottom of the condenser, and is carried off by the overflow-pipe 11, to the tender R; but when a supply of water is required for the boiler, the engineman opens the hot-water feed-cock 13, which allows a certain portion of the hot water from the overflow-pipe to pass into the hot-water pump, from which it is sent through the tubes 3 3, contained in the lower heating chamber L L. These tubes being surmounted, at the same time, with the exhaust steam, direct from the blast-pipe, the feed-water acquires a proportional further heating, and is then passed to the boiler by the pipe 6. Both pumps are provided with suitable cocks and clack-boxes, so that, should a failure occur in either heating apparatus, the water may pass from the pumps direct to the boiler, and work as an ordinary engine."

November 18, 1856.

GEORGE P. BIDDER, Vice-President,
in the Chair.

The discussion upon the Paper No. 949, "On the Improvement of Railway Locomotive Stock, &c.," by Mr. D. K. Clark, was continued throughout the Meeting, to the exclusion of any other subject.

SELF-ACTING PENSTOCK, OR FLUSHING MACHINE.

After the Meeting, Mr. ROGER SALTER explained two models of his Self-acting Penstocks, or Flushing Machines, for cleansing house drains and sewers. These machines were of two kinds, the one having a valve hung horizontally, the other a valve, or gate, hung vertically. In house drains a tank, or cesspool, was formed, for the collection and retention, during one day, of all the waste water running from the house, and this water, which would otherwise possibly help to create the necessity for flushing, was used as the flushing medium. If the rain water also was allowed to run into and collect in this tank, then the number of flushings would be increased. Although it was not contended, that the construction of flushing-tanks was a new idea, yet it was believed that the mechanical arrangements for making them self-acting were novel and important. The mode of accomplishing this was very simple:—A cast-iron pipe was fixed to the bottom of the tank, and on a level, or nearly so, with the bottom of

the drain. A valve was hung so as to fall on the outlet of this pipe, the beat for the valve having a considerable angle. To keep this valve closed, and to prevent the water from escaping, a strut, or stopper, working on a centre, fell dead on the valve, and held it close to its seat, thereby securing a water-tight joint. To release the water when it had risen to the discharging point in the tank, a waste-pipe conveyed the overflow to a tilting basin, or bucket, hung on centres, at a convenient height above the valve. Beyond these centres an arm, or lever, extended, to which was attached a weight to counterpoise the bucket, and a rod connecting the lever with the strut. When the weight of water in the bucket caused it to tilt, or drop down, the lever and connecting rod at the opposite end of the basin, or bucket, rising by the tilting of the bucket, carried up the strut and released the valve, and the contents of the tank were suddenly discharged into the drain. By means of a moveable lid, the bucket was made to empty itself, while the contents of the tank were being discharged. When the water was all out of the bucket, the balance-weight caused it to recover itself, and in doing so again fixed down the valve, by means of the strut before referred to. These machines had neither latch, catch, nor spring, which by corrosion would impede their action. They were made of cast-iron, and were said not to be liable to get out of order. They had been used by the Honourable Board of Ordnance for the cleansing of barrack-drains. The arrangement in these cases consisted of an elongated cesspool, or invert, having a self-acting flushing machine fixed at the outlet, so that when the water in the invert had risen as high as was required, the machine acted, and the whole of the contents of the cesspool, or invert, were at once discharged into the drain, and swept away. In cavalry barracks large quantities of hay, straw, and other matter, were thrown into the invert, yet no inconvenience had hitherto arisen in their use.

It would be readily seen that these machines could be applied to tanks in all situations, as no head of water was required, and they might be of any capacity.

In the self-acting flushing gate, the gate was entirely closed across the whole width of the sewer, and was of any convenient height. The gate was kept closed by means of a strut jointed in the centre; one end of the strut worked in an eye fixed in the centre of the gate, whilst the other end worked in an eye fixed to the wall of the side entrance. The tilting basin was hung on centres within the side entrance, so as not to interfere with the opening of the gate; the lever extended beyond the centres, and underneath the joint of the strut. The water having risen behind the gate to the discharging point, a waste-pipe took the overflow water into the tilting basin, or bucket, when the lever raised the joint

from the horizontal position, and the weight of water pressing against the gate, caused it immediately to fly open, and the scour took place. The legs of the strut, by the two extremities being brought closer together, formed the two legs of the letter A. When the rush of water had subsided, the legs of the strut, from their position, had a tendency to thrust the gate from them, and the more nearly the legs of the strut assumed a horizontal position, the greater was the thrust, so that the gate was eventually forced home.

November 25, 1856.

ISAMBARD K. BRUNEL, Vice-President, in the Chair.

On taking the chair, Mr. Brunel announced to the Meeting the decease, on the 21st instant, of Mr. James Meadows Rendel, Past President of the Institution. He therefore proposed, as a mark of respect for the memory of the late distinguished Member, and in order to testify the general sense of the great loss the profession had sustained, in the decease of one of the oldest and most eminent Members of the Institution, that the Meeting should be adjourned. This proposition was unanimously agreed to, several Members availing themselves of the opportunity of expressing their respect and esteem for their late friend, and their sympathy with his family for the heavy loss they had sustained.

A Memoir of Mr. Rendel will be found in the Appendix to the Annual Report.

December 2, 1856.

JOSEPH LOCKE, M.P., Vice-President,
in the Chair.

THE following Candidates were balloted for, and duly elected:—Charles Cheyne, Henry Conybeare, Samuel Dobson, and James Ramsden, as Members; Samuel Bagster Boulton, John Cameron, Isaac Curran, Charles Augustus Hartley, John William Heinke, Alexander Grainger Linn, Edward Price, William Mackenzie Shaw, Augustus Siebe, and Alexander Robert Terry, as Associates.

No. 951.—"On recent Improvements in Water Meters." By THOMAS TAYLORSON JOPLING.

THE subject of Water Meters having recently engaged the attention of this Institution,[1] and the merits of the best piston and bucket meters having been fully discussed, it will not be necessary, in introducing the main subject of the present Paper, to say more in relation to those machines, with the construction of which Engineers are very familiar, than that the two classes of meters possess certain generic merits, which are generally appreciated; and also certain generic defects, which are apparently inseparable from them, and have only as yet been partially removed. The merits and defects of these two classes of meters were concisely stated in a Paper[2] by Mr. C. W. Siemens, Assoc. Inst. C.E., read before the Institution of Mechanical Engineers at Birmingham, on the 25th January 1854. In relation to bucket meters he says, "It would be interesting to add to the list of bucket meters, contrivances both cheap in construction and capable of measuring liquids with accuracy, were it not that these meters destroy the onward pressure of the water, and are of necessity incumbered by cisterns at elevations above the premises supplied, which cisterns entail great expense and inconvenience."[3] And with respect to the piston meter, he remarks, that it has "the advantage of transmitting the onward pressure of the water, and of dispensing with the necessity of a cistern. On the other hand it labours under great and peculiar disadvantages, partly on account of the valves and pistons which are employed being quickly destroyed by the

[1] *Vide* a Paper by Mr. David Chadwick, read May 2, 1854, Minutes of Proceedings, Inst. C.E., vol. xiii. pp. 421–430.

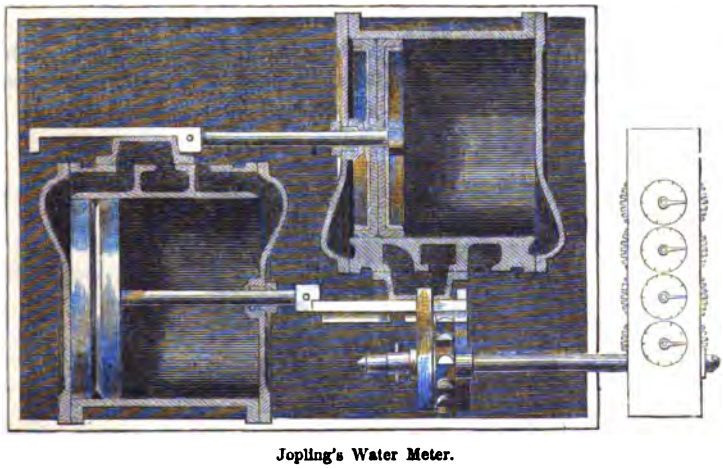
[2] *Vide* Institution of Mechanical Engineers—Proceedings, 25th January, 1854, p. 6.

[3] Ibid., p. 8.

sand and other impurities contained in the water, or broken by its impact against them, and partly on account of their great bulk and expense, in proportion to the water measured." [1]

Now, it is the object of the present Paper to introduce to the notice of the Institution of Civil Engineers, a piston meter, (designed and constructed by the Author,) which, it is believed, will in great part, if not wholly, meet and remove the objections thus advanced against meters constructed on the piston, or diaphragm principle. The meter may be described as consisting of two measuring cylinders, set parallel to each other, provided severally with a working piston, the rods of which project out of the cylinders in opposite directions, and carry at their extremities a slide valve frame, for supporting and working the slide valves that govern the ports of the adjacent cylinder. These measuring cylinders are contained in a cast-iron case, or tank, into which the water to be measured enters under a certain pressure. The water passes thence into the cylinders, from which, after having acted upon one, or other of the pistons, it makes its escape. Through the agency of suitable counting apparatus, connected with one of the piston rods, the number of the reciprocating movements of the piston is counted; and thus the quantity of water passed through the meter in a given time, is indicated. Fig. 1 shows the meter in sectional

Fig. 1.



Jopling's Water Meter.

plan view, the upper part of the cast-iron case being removed to exhibit the construction and arrangement of the measuring cham-

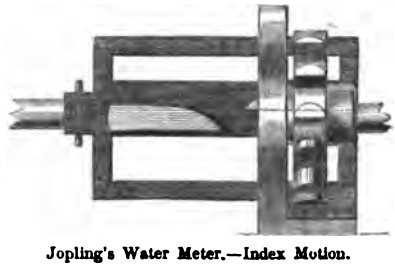
[1] *Vide* Institution of Mechanical Engineers—Proceedings, 25th January, 1854, p. 9.

bers, and the moving parts in connection with them. The measuring chambers are made somewhat like ordinary steam-engine cylinders, as respects the inlet and outlet ports: but in one of the cylinders the direction of the inlet ports is inverted; in order that the right-hand port may pass the water to the left-hand end of the cylinder, and the left-hand port to the right-hand end. By this means the two pistons are enabled to follow each other in the same direction, and to maintain the continuous action of the meter without the use of cranks. The slide valves are pressed up against the ports of the cylinder by means of springs, in order to retain them in contact with the faces, when the meter is at rest; and they are free to remain stationary, during the greater portion of the progress of the pistons; but just as the piston of one cylinder is completing its stroke, one of a pair of tappets on the valve frame, carried by the piston rod of that cylinder, will strike against the valve which that valve frame carries, and change its position over the ports of the other cylinder; whereby the direction of the flow of water into that measuring cylinder is reversed.

It will thus be understood, that the movement of the piston of one cylinder will govern the supply of water to the other cylinder, and *vice versâ*. A continuous influx and efflux of water is thus effected, in the two cylinders; and the discharged water from both cylinders meets in a common passage, and escapes, in a continuous stream, from the meter.

The manner of transmitting the reciprocating motion of the pistons to the index is very simple (Fig. 2). For this purpose,

Fig. 2.



Jopling's Water Meter.—Index Motion.

one of the valve frames is furnished, at the back, with two ribs, or feathers, set parallel to each other, but one being in advance of the other. These feathers act as teeth, and, in sliding backwards and forwards with the piston rod, enter alternately the teeth of an escape wheel, and so drive it round tooth by tooth. The arbor of this wheel leads through the water case to the count-

ing apparatus; and thus motion is communicated to it, without the aid of pawls and ratchet wheels, or other complex apparatus.

From this description of the construction and operation of the meter, it will be understood that simplicity of construction has been studied throughout; and that the use of cranks, excentrics, and slide rods, being dispensed with, the meter is reduced to a very simple and inexpensive machine, having but four moving parts, viz., the pistons and valves of the two cylinders. Examination of the working of the meter will show, that the tendency to concussion, which was referred to in Mr. Siemens' paper, as incidental to all piston meters, is, by this arrangement, entirely removed. The tappets on the slide-valve frames of the advancing piston are made to move the position of the valve, which governs the ports of the cylinder, whose piston is just completing its stroke; and thus to check the supply of water to the receding side of that piston; so that the piston is brought gradually to a state of rest.

By enclosing the measuring cylinders in a water-tight case, as explained, two important advantages are secured, viz.:—First, the pressure (however great may be the head of water) is equalized on the interior and exterior of the cylinders; and the valves will work with comparatively little friction. The meter may also be made very light, and even with gutta-percha cylinders if required; and there is little tendency to leakage. Secondly, the case, which sustains the pressure of the water (and may be made of cast iron of any sufficient thickness) acts as a deposit chamber for sand, stones, and other extraneous matters, which will have no tendency to enter the ports, but will settle, by their own gravity, at the bottom of the case. Thus provision is made for the removal of another defect, hitherto considered incidental to piston meters.

Some merit, on the score of simplicity, may, perhaps, also be claimed for the mode of converting the reciprocating motion derived from the piston rod, into an intermittent rotary motion, for driving the counting apparatus, and indicating the amount of water passed through the measuring chambers.

As respects the actual results of the working of the meters, the Author would prefer the independent expression of the experience of those Engineers who have used them, particularly as they are comparatively of recent introduction. He may, however, state, that Mr. Knott, the out-door manager to the Sunderland and South Shields Water Company, at whose works the meter has been used, says, in a communication dated Sunderland, September 18th, 1856:—

"In answer to your inquiry as to how your meters are going on, I have to report as follows:—

"You are aware that I connected one of them with one of Parkinson's on the 17th July last, and one with another of the

same maker on the 4th August. I find, up to this date, that with a slight uniform difference per cent., these four meters have registered alike.

"I also connected another of your meters with one of Kennedy's, of Kilmarnock, on the 1st August, and find that, up to the present time, these two meters have registered exactly alike.

"I consider, therefore, that the performance of your meters, attached to the works of this Company, to be so far exceedingly satisfactory; and from the simplicity of their construction, and non-liability to derangement, to be the best kind of high-pressure meter that has come under my notice."

The meter has also received the verbal commendation of several Hydraulic Engineers of eminence. The Author, therefore, with some confidence, submits it to the judgment of the Institution, as a step in advance, if not a realization of what has been so long desired, not merely by Water Companies, but by the public.[1]

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[1] Since this Paper was written, the Author has introduced a 2-inch meter, for measuring hot as well as cold water, for steam-boiler purposes, &c. It is slightly different in construction to that described in the Paper, though the same arrangement is preserved. One of the two cylinders is made of a, comparatively, large diameter, whilst the other is quite small, being simply employed to move the valve of the larger cylinder, and to prevent concussion. The index is moved by the large piston, and is made to measure the length of stroke given by it, so as to insure a perfect registration, under any pressure, or length of stroke. This meter occupies a very small space.—[T. T. J., August, 1857.]

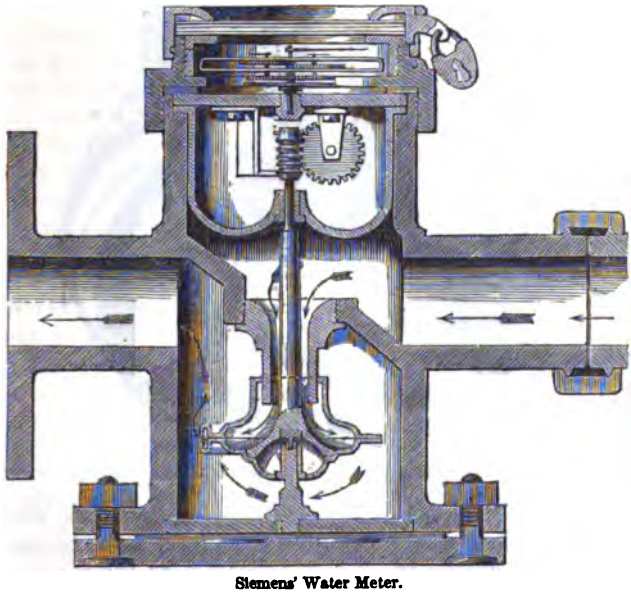
Mr. JOPLING

Mr. JOPLING said, that when only a small portion of fluid passed through at a slow rate, the pistons would not quite pass to the end of the stroke; though it required very little additional pressure to force them to the end. He had therefore introduced a means of gauging the length of each stroke, accurately, when valuable liquids were being measured.

Mr. SIEMENS remarked that, the chief desiderata for high-pressure meters were:—accuracy of measurement under very varying speeds and pressures,—free passage for the water without sensible loss of pressure,—compactness and lightness of construction,—with durability and cheapness.

He believed that he was the first to bring a high-pressure meter into practical use. His meters were of the class termed "inferential" measurers, and so many of them were now in actual and satisfactory use, that it was unnecessary to give any minute description of their construction. The only moving part, except the counter, was a drum of corrugated metal, of simple construction, and perfectly balanced upon a fixed stud (Fig. 3). At the bottom

Fig. 3.

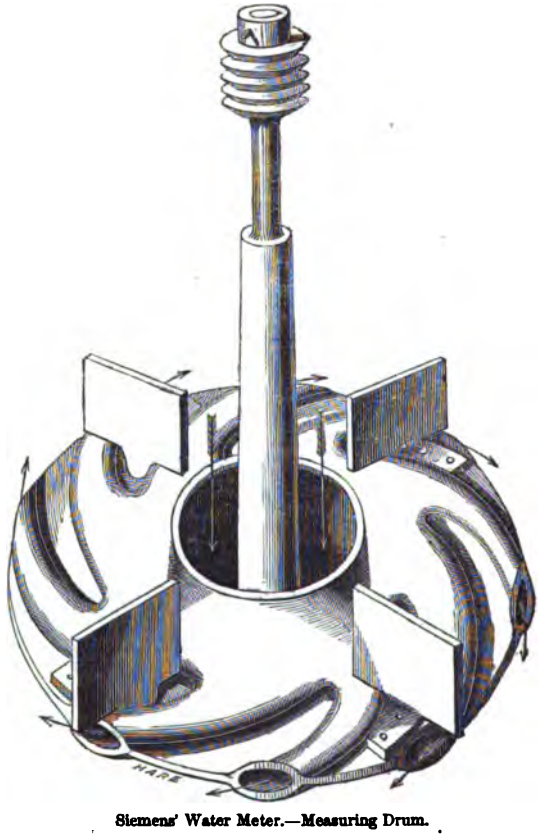


Siemens' Water Meter.

of the drum an inverted oil cup was placed, into which the fixed stud entered. It was a steel point working against a steel plate, and being well lubricated, the bearing friction was reduced to a small and constant quantity. The friction and wear and tear did

not increase with the velocity, for at high speeds, the drum being balanced and without lateral pressure upon the bearings, would revolve on its mechanical axis of rotation, like a top, or gyroscope. The action of these meters was similar to that of the Barker's mill, the water entering at the centre (Fig. 4), and being expelled

Fig. 4.



Siemens' Water Meter.—Measuring Drum.

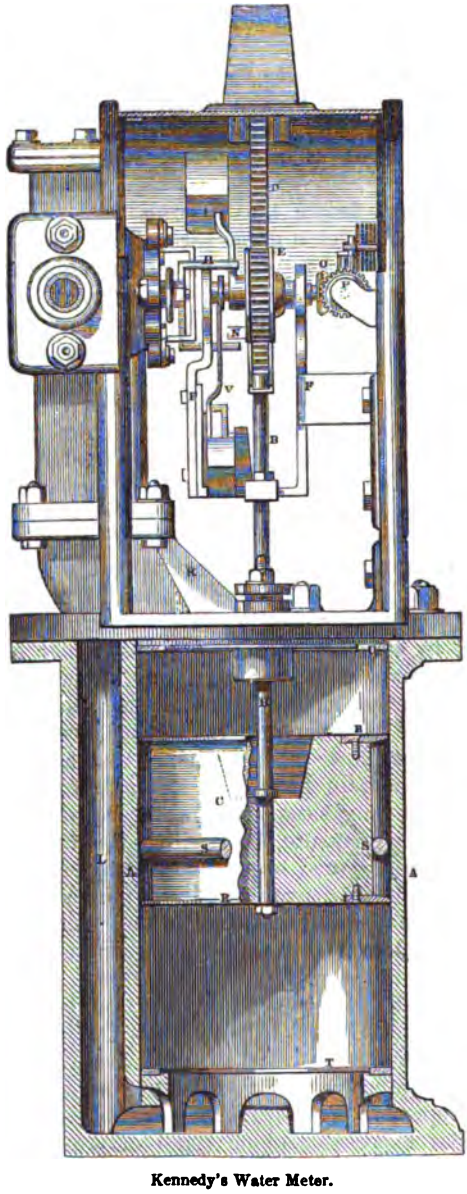
through numerous curved orifices at the periphery of the revolving meter. This alone would not give a uniform rate, because the power of the hydraulic wheel would increase as the square of the velocity. Therefore it was necessary to attach vanes to effect a resistance, increasing also as the square of the velocity. By that means uniformity of measurement was obtained. These meters offered great security against derangement, and out of the 2,000 or 3,000 that Messrs. Guest and Chrimes, the manufacturers, had

supplied, only about 2 per cent. had been returned as defective, during the last twelve months. In most cases, the derangement had arisen from the breaking of the vanes, which were riveted and soldered to the drum itself. When revolving at high speeds, the pressure of the water upon the vanes of the larger sizes was great, and some of them had broken away, but this defect was now entirely remedied. He thought a meter constructed upon this principle offered great security of registering permanently and satisfactorily.

The other meters before the Meeting were of the piston and diaphragm class, of which a great variety had been proposed, and some of the contrivances resorted to for reversing the movement, and diminishing friction, were very ingenious. No doubt a good piston meter might be made to register excellently, during laboratory experiments and for short periods; but the real test was the action after twelve months' constant work. By that time it was generally found that some injury had occurred to piston meters, from the introduction of sand, or other extraneous matter, and a small scratch on the face of the valve, would suffice to pass a considerable quantity of water without measurement; whereas the action of the inferential meters was as perfect, after several years, as when first they were erected. Arguing that a certain force was required to cause motion, it had been stated, that the inferential meters were not capable of registering small quantities of fluid at low velocities. That this was, however, an erroneous opinion, was demonstrated by the fact of a small house meter having moved with so small a quantity as half a gill per minute. These meters gained in sensitiveness as they worked, whereas piston and other meters were liable to wear and tear; the former could be so applied as to present little more resistance than a bend in the pipe; they were so compact in form, and so small, that they could be adapted to almost any situation however restricted; and under either high, or low pressure, and with constant, or intermittent action, they had been found to give satisfactory results.

He had no wish to disparage Mr. Jopling's meter, for there appeared to him to be a great deal of ingenuity displayed in its construction, and it seemed that in this instrument the concussion in the pipes, upon the shutting off of the water, at each change of stroke, was avoided. There was one objection, however, which the Author himself had referred to, which was that the piston did not always travel to the end of the stroke. That would be a serious inconvenience, because a slight difference in the length of the stroke would represent a considerable error in the measurement of the meter. But experience alone could determine how far durability and facility of application, which were essential desiderata, could be obtained by it.

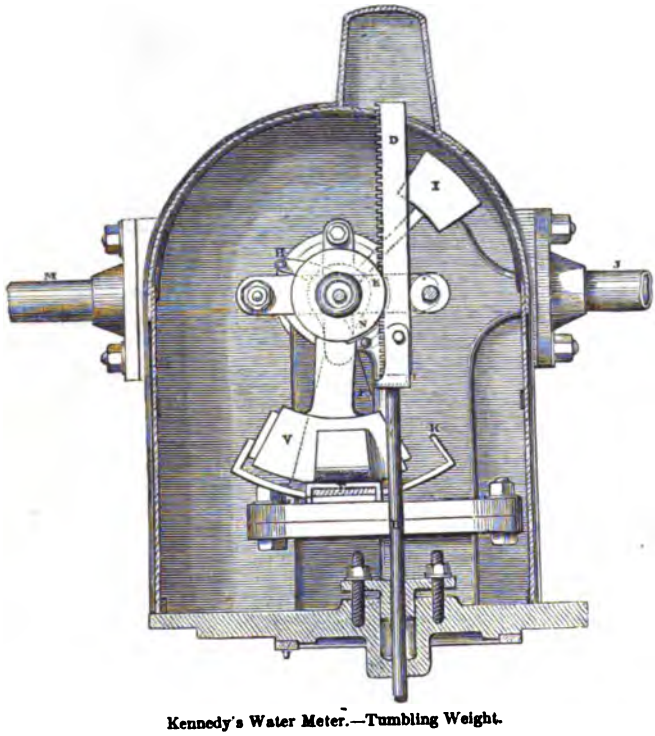
Fig. 5.



Kennedy's Water Meter.

Mr. KENNEDY said, that his meter (Figs. 5, 6, 7, and 8) was constructed on the principle of measurement by capacity. It consisted of a single vertical cylinder, wherein a deep piston worked, with a vulcanized india-rubber ring packing, made to roll between the piston and the cylinder. This packing allowed for easy motion, and yet was perfectly water-tight, with very little friction. The alternate action of the piston was communicated to the counting apparatus, by means of a rack and pinion, and action was given to the inlet and outlet valves by means of a tumbling weight.

Fig. 6.

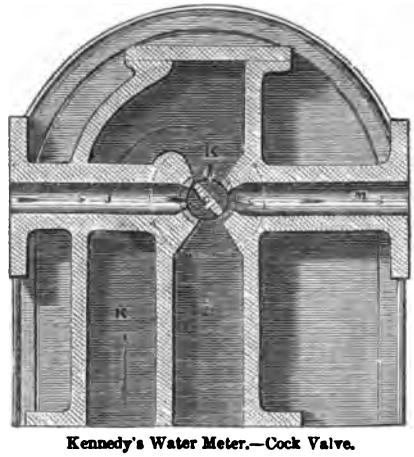


Kennedy's Water Meter.—Tumbling Weight.

This machine was very durable, and was easily kept in order. The elasticity of the packing, and the peculiar rolling motion diminished the friction. The pressure of the water was preserved through the meter; and the action of the valves was so regular and simple, that under the most extreme trials the variation had never been found to exceed one per cent. Indeed it could be said to measure correctly and uniformly under every variety of pressure

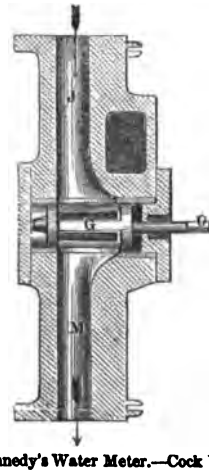
and flow, and the amount of head pressure required to work it was so small, that in rare instances only would it be of any importance.

Fig. 7.



Kennedy's Water Meter.—Cock Valve.

Fig. 8.



Kennedy's Water Meter.—Cock Valve.

These meters had been extensively employed, and were much approved by Engineers of Water Works.

Mr. GREAVES could confirm the opinion which had been expressed,—that the accurate measurement of water was of importance alike to the Engineer, the manufacturer, and the public

generally. The cost of water was, to a certain extent, dependent upon the degree of waste to which it was subjected; and any saving, or a more accurate account of the quantity required and delivered, must be advantageous both to the consumers and to those who supplied it. Hitherto the difficulties in the way of measurement had been very great. Before meters were constructed they were obliged to measure the cisterns, and to ascertain, by the flow of the pipe, how much it would deliver per day, or per hour, and to charge the consumer accordingly. But there were many inconveniences attending this mode of proceeding. Cisterns were various in size and irregular in shape, and sometimes they were placed in out-of-the-way situations.

The exact form of meter which would eventually be adopted was more than could be predicted. Many trials had been made, and he had assisted numerous inventors in experimenting with instruments, some of which had merit, but the majority were failures. The difficulties in perfecting piston meters were considerable; and although there was much ingenuity in that of Mr. Jopling, yet he was afraid that there were defects in it, that would not allow of its coming into general use. He was not in favour of slides. From what he had seen of them they were liable to wear round, or if they were so strongly guided as to prevent their rubbing irregularly on the surface, they were apt to wear off from the face, and then the correctness of the meter was vitiated. Independently of this, the pressure of the slide must vary with the pressure of the water behind it. This could not be fixed at any one limit, as the pressure by day would always be less than that by night. He had never yet heard of an apparatus that could be attached to a meter to regulate the pressure and render it uniform; and if a slide was subject to varying pressure, it must necessarily produce an erroneous registering in the instrument. In Mr. Siemens' and Mr. Kennedy's meters the friction was uniform. In the former this was accomplished by balancing the increasing ratio of the retarding vanes against the increasing ratio of preasure due to the centrifugal force. These were made so nearly equal as to produce an uniform correct reading. The piston of Mr. Kennedy's meter was an excellent contrivance, and was an improvement upon any other piston which had yet been tried for purposes of this kind. The elastic diaphragms used in several other plans were, he thought, a failure. They were apt to crack, and they gave an erroneous and irregular measurement. He did not believe that the tightness of the piston was of much importance, because the instrument had nothing to drive, and it was not necessary that the piston should be tight. The friction of the slide and the counter was all that the piston meter had to overcome.

The point in which Mr. Jopling's meter chiefly differed from others was, that the indicator only gave a register of the number of strokes. This alone would not give a correct result, as the length of stroke of the piston would vary as much as from half an inch to three quarters of an inch, according to the pressure turned on. Therefore, unless there was something to add in the extra lengths, there must be an incorrect reading. In another meter of this character an apparatus had been added, which, by means of a second escape catch on the wheel, gave the surplus at the end of a certain number of strokes, in addition to the ordinary registration. A more accurate measurement was obtained by this means, but there was complication in it, and that was very objectionable. In Mr. Kennedy's meter a rack attached to the piston rod, drove a cog wheel, from which the counting motion was taken. Therefore, whatever length of stroke the piston made, an equivalent number of cogs on the wheel was moved; and whether the length of the stroke was half an inch, or six inches, was a matter of indifference, as the counter wheel added up the length of all the strokes. There was no reason why this modification should not be applied to Mr. Jopling's instrument. In Mr. Kennedy's meter the alternating admission of the water was managed by a cock reversed by a tumbler weight, somewhat on the principle of a planing machine.

He had used this meter for measuring the quantity of water evaporated from boilers. It was of great importance to those who had charge of engines, to be able to ascertain the relative effective value of the boiler and of the engine. In measuring the work done against the coals consumed, the work of the engine and the boiler were mixed up together; whereas by measuring the water evaporated, a distinction was made between the two. He had placed this meter upon a set of boilers, the engine attached to which gave 200 horse power in water lifted. The quantity of water evaporated was a little more than eight gallons per minute. The apparatus did not cost more than £10, and yet it gave a certain indication, whether the defects were in the boiler, or in the engine.

He had used Mr. Siemens' meters extensively, and at the present time the East London Water Works Company had about two hundred in operation, the average cost of which, taking all the sizes, was about £10 each. During the last quarter that Company received £5,000 rental for water delivered by meter. The use of the meters induced a decrease in the quantity of water pumped, and at the same time a larger rental was received for what was delivered. But few failures had occurred with these meters, and these were quite capable of being remedied, so that casualties were likely to be even less frequent in future. Mr.

Kennedy's meter had also worked very well, and, up to the present time, the meters of Mr. Siemens and Mr. Kennedy were the only instruments on which implicit reliance could be placed.

Mr. JOPLING remarked that his meters worked very easily and without shock. Some experimental meters indicated half a gallon each on the dial with the greatest accuracy. In a three-quarter inch meter, making four strokes to each gallon, the slides, after having passed upwards of a quarter of a million gallons of water, exhibited scarcely the slightest appearance of wear, so that the fear expressed respecting the wearing of the slides was proved to be groundless.

Mr. JAMES SIMPSON said, that this subject had occupied his attention for many years, during which time he had seen a great number of different meters, and had tried many of them. The first meter that he saw, was that invented in the year 1810, by the late Mr. Joseph Bramah. It was on the same principle as the rotary steam-engine invented by the same gentleman, and consisted of an excentric drum within the cylinder,—with protruding vanes, or slides. It was represented to be a good water meter, but unfortunately it did not register variable velocities correctly, or even approximately. Mr. Mitchell, of Glasgow, also brought out a meter, which seemed, at the time, to possess the elements of success. This was an attempt to introduce a spiral screw into a pipe, with vanes to counteract the effects of velocity, as had been described by Mr. Siemens, but it did not register correctly under variable pressures. Mr. Stirling, of Dundee, brought out a bucket meter, which measured accurately, but it was not adapted to measure water under pressure, and in many instances it could not be conveniently applied. This class of water meters should not, he thought, be lost sight of, for they might answer well, where the water could be delivered immediately into receptacles. Mr. Siemens' meter had been extensively applied at the Bristol Water Works, and had been found to work well, not only for the public, but for the Companies, and by its use fair rates were obtained for the water supplied. He was inclined to think that of high-pressure meters this was at present the best. He was much struck with the excellent workmanship of Mr. Jopling's meter; and its arrangement, as a first attempt, was so good, that he thought it well deserving of notice. With some modifications, and the means of recording the length of each stroke, he should be induced to give it a fair trial. He had tried Mr. Kennedy's meter, and found it work excellently; indeed as a piston meter it might be looked upon as the best. At first, the regurgitation of the water, owing to the alternating action of the machine, induced sudden shocks, which caused the pipes to burst; but this defect had now been overcome. It was most desirable to

check waste of water, and nothing would so certainly insure this result, as the introduction of efficient meters. At present he imagined all large consumers would prefer to be supplied by meter. The question of water meters had engaged the attention of Engineers in America; but it did not appear that they had made any greater advance than in this country. They had meters in the Water Works at New York and at Boston which worked well, but not better than those in use in England. What constituted the difficulty in the way of making a good water meter was the varying pressures of the water in the pipes. Personally, he was satisfied with that class which indicated the quantity of water passed, by the velocity of its flow in a line of pipe, but all consumers ought to be made to understand the application of these meters, and the result of their working. A portion of the public imagined, that because the water was passed through the meter in a connected pipe, and was not measured into a vessel, that the quantities could not be ascertained correctly. This was a prejudice to be overcome. It might appear singular, that in Water Works, which had been in such active operation in England for the last half century, so little should be known about good water meters, or their practical application; it was a fact nevertheless that, until within the last ten years, the use of water meters in England was extremely limited, and even now they could not be trusted implicitly.

Mr. HAWKSLEY corroborated the opinion just expressed, that until within the last few years, no means for measuring the water supplied by Companies had been applied. At the present time, however, there were, at least, eleven distinct classes of meters, and perhaps there were not less than ten inventions coming within each class, so that there could not be fewer than one hundred different kinds of water meters. They were divisible into two classes, which were respectively called high-pressure meters and low-pressure meters. The meters which sustained the direct pressure of the water in the mains, and delivered the water without any sensible diminution of the pressure, were termed high-pressure meters; while, on the contrary, low-pressure meters were those which received the water at the pressure of the mains, but delivered it, without pressure, into a cistern, or other receptacle. With regard to these two classes of meters, it might be observed, in the first instance, that, as a general rule, the low-pressure meters were in principle the best. In nearly all cases it was advisable to apply a meter, to ascertain the quantity delivered, but more especially where the consumption was large and irregular, as in breweries, dye-houses, and manufactories of almost every description. Dyers, bleachers, calico-printers, and others, required a pipe 3 inches in diameter, to run off, in two or three

minutes, into a sunk vat, many hundred gallons of water, and then suddenly the flow would be stopped. This caused great inconvenience to a Water Company, who, in this case, must have its main in that street, not in proportion to the quantity which was taken by the manufacturer in any continuous period of time, but to the rate at which it was intermittently delivered, during the time the water happened to be drawn. Moreover, by thus suddenly opening and shutting the taps, a great shock was brought upon the pipes of the consumers for some considerable area around, as well as to those of the Company, and, where the pressure was great, this was objectionable. On the other hand, if a low-pressure meter were used, the meter must be placed at the upper part of the building, and the water must be received into a cistern. Though this plan might appear to involve a small apparent cost to the consumer, it had this advantage, both to the Company and to the manufacturer, that the latter could drain the water out of the cistern through a large pipe of his own, and under a light pressure, without occasioning any shock in the pipes of the Company, or the danger of bursting his own pipes. The wear and tear on his own pipes was so much diminished, that the reduction in the cost of repairs would pay for all the apparatus required to be put up. The cistern had only to be of sufficient size to receive the necessary quantity of water, during the intervals in which it was drawn, to meet each demand.

For the supply of locomotives on railways, Mr. Hawksley had erected meters delivering large quantities of water. In those cases he had found it desirable, to discharge the water into cisterns, in a regular stream, by a low-pressure meter, rather than to discharge it at once into the engine.

The piston meter was, he believed, the oldest form of instrument. He had made them as far back as 1833, in conjunction with Mr. Blaxland, a gentleman well known as one of the earliest introducers of screw propulsion. He then found, that nearly all the pipes were liable to be burst, by the reciprocating action of the valves. That had been, in some measure, overcome by Mr. Kennedy and others, who had introduced a means of preventing the sudden "check" of the water. In Mr. Kennedy's meter, the action of the tumbler upon a cock, which, while changing the direction of the current, never perfectly closed, did, in fact, prevent the shock, but it introduced a source of error in the registration, though usually of small amount. He had seen Mr. Jopling's, Mr. Kennedy's, and other piston meters at work, and he must say that they had been so improved, that he thought they were generally applicable to the purposes of Water Companies. A combined oscillating and piston meter had just been brought out which promised to work well. Its action was much

the same as that of an engine by which Mr. Sims, of Cornwall, pumped water, by driving a heavy weight from one end of the piston to the other.

Another form was the diaphragm meter, invented by Mr. Parkinson, of Bury, Lancashire. That failed for two reasons;—first, because the slide valves did not, after a time, work correctly, but, principally, because the india-rubber diaphragm was found to fail, after a limited number of reciprocations.

The puff-bag meter, which was simple in construction, consisted of two vessels, formed of elastic material, which folded up in the manner of a smith's bellows; these were enclosed within the case, into which the water was admitted. As these meters only experienced a differential pressure, they were not much strained. The bags were placed beside each other, and were alternately filled and emptied, by apparatus of a simple character. After a time, however, the materials of which the bags were made, were found to become less elastic, and ultimately gave way at the folds.

The screw meter, which was a Scotch invention, depended upon the principle of the force of the water in motion, being as the square of the velocity. It had a long threaded screw, upon which the water acted by impulse. That failed, because it would not register equally at all velocities, and because, after it had been in use for some time, the friction of the machinery materially increased, while the force of the water remaining the same, the registration unavoidably became slow.

The meter of Mr. Siemens, which resembled one by Mr. Adamson, of Leeds, was, in principle, simply a turbine, or a Barker's mill, partaking of the errors of those machines, which no superiority of manufacture, or skill in invention, could entirely overcome. It could not register so small a quantity as would not give impulse to the machine. It had been remarked that, in some situations, it was liable to become corroded, which materially lessened the speed, and in some instances the meters had actually been stopped. It was liable to this objection, that while the friction was as the first power of the velocity, the force of the water by which it was set in motion, was as the second power of the velocity. Hence, if the meter was adjusted to a medium velocity, it would be slow in registration when the water was flowing at a low velocity, and fast when flowing at a high velocity. To correct this source of error, Mr. Siemens had introduced a system of vanes, to give an increased resistance varying as the square of the velocity. That resistance being considerable, absorbed, to a certain extent, the friction which was as the first power. It made it less sensitive; but there was this difficulty, the friction of the machinery became greater after it had been some time in use, and the meter became slow. Another objection was, that having the

friction as the first power, any person wanting water through the meter, might get a large quantity of water after the meter was deteriorated by age, without any registration at all. That objection did not apply, however, in places where the service was intermittent, and the water was usually drawn with rapidity; but rather to the large number of cases in which the supply was constant from the main. Where the supply was to feed a boiler, the water was driven through gently, and, after a time, the register fell short of what it ought to be.

Mr. Hawksley had used the wheel meter in a very large number of instances, and he had never once found it unsatisfactory, as regarded accuracy of registration.

As far as his experience went, it was to the interest of every Water Company to employ low-pressure meters, where applicable, in preference to high-pressure meters. There were cases in which the former were not applicable, and then, of course, the best high-pressure meter must be applied. Perhaps there was no case in which the Water Companies were, generally, more unfairly treated, than in supplying water for watering the streets. Low-pressure meters, with cisterns, were inapplicable for this purpose, but a high-pressure meter might be advantageously applied, as the water could be drawn through the meter into the carts, and the quantity delivered be ascertained.

Mr. RAWLINSON confirmed the remark, that Water Companies ought to insist upon the use of the best description of meter, for every purpose of trade at least. He believed that such a practice would induce a saving to consumers, and economy to the Water Companies, who would, he felt convinced, receive, in the first year, such an increase of rental for the quantity supplied, as to more than pay the cost of meters, which ranged in price, according to size and description, from £3 each and upwards. Experiments had recently been made, at Lancaster, with various kinds of meters, and he had been informed that that of Mr. Siemens only differed about 2½ per cent. under a pressure of 200 feet. He had used this meter in several towns, with satisfactory results. Care must be taken not to allow these meters to measure air, which they would do with an intermittent supply of water.

Mr. SIEMENS expressed his surprise at the statement of Mr. Hawksley, that his meters had been found to register slow after having been some time at work. He had in all cases remarked the opposite effect; and at Bristol, where a considerable number were at work, and where they had been tested every three months, they had been observed to gain from 1 to 2 per cent. The new meters were consequently adjusted 1 per cent. slow before they were sent out. Experience had generally shown, that after the meters had been in use some time, they worked more freely. With regard to

the objection to the principle, he had no hesitation in admitting that his meter would allow a certain small quantity of water to pass unmeasured; but he maintained that this was of no practical consequence, because the water that could trickle through the meter would be small in amount and of little value. In proof of this he might mention, that the smallest size of meter, intended for house purposes, and which had been just brought out, would move with so small a quantity of water as one-eighth of a pint passing through it in one minute, and would give correct measurement when one-fourth of a pint per minute was passed through it. If this meter was kept under constant service, day and night, for three hundred working days, the money value of one-eighth of a pint passing per minute would amount to about six shillings a year.

Mr. HAWKSLEY said, he had no prejudice in favour of any particular meter. In Nottingham, and other towns, Mr. Siemens' meters had not succeeded under the circumstances he had stated. The fact was, that a meter which had any friction must allow water to pass, in a small stream, without registering it. He admitted, however, that that class of meter was very good for registering high velocities.

Mr. LOCKE, M.P., V.P., remarked, that all the speakers had agreed, that much yet remained to be done, in order to obtain an efficient water-meter; and whilst this was the case, they ought to be the more grateful to those who brought the subject before the Institution.

Mr. DAVID CHADWICK, through the SECRETARY, called the attention of the Members to a rotary water-meter, intended for the measurement of water at different velocities, and under all circumstances of supply and discharge. It was described to consist of three, or more rollers, revolving on their axes, which were attached to the periphery of a wheel, the spindle of which worked in journals fixed in two upright supports. These rollers rested upon a bag of prepared leather, with inlet and outlet passages, and so fixed upon a concave bed-plate of brass, as to form the measuring chamber of the meter. The water being admitted into the bag, propelled the rollers forward, so that they each in turn passed over every part and expressed the fluid before them, into the outer, or iron case of the meter, whence it issued by the outlet pipe. The motion was regulated by a governor, consisting of a spiral fan, and moving in an opposite direction to the rollers. The counting apparatus was identical with that in the old meter, described on a former occasion at the Institution.[1] These meters had not been very long in use; but, as far as could be at present seen, they might be called successful.

[1] *Vide* Minutes of Proceedings Inst. C.E. vol. xiii., pp. 421–430.

December 9, 1856.

GEORGE P. BIDDER, Vice-President,
in the Chair.

No. 945.—"On the Laws of the Strength of Wrought and Cast Iron." By WILLIAM BELL.

IN the following Paper, the chief point has been the consideration of the longitudinal, as compared with the transverse, strength of wrought and cast iron, upon principles generally received, and as modified by recent experiments.

It has long been known, that in examining experiments on tearing asunder, or crushing, bars of cast iron, and those made by breaking bars transversely, the same results were not arrived at; and the difference being hitherto unexplained, it appeared that the most satisfactory method of investigation would be, to take the whole of the experiments, made up to the present time, and from them, and the known formulæ of elasticity, to deduce such values of the constants in the formulæ, as would satisfy each experiment individually. By then comparing these values among themselves, and with the particulars of the experiments from which they were derived, a general view of the accordance, or non-accordance of theory with experiment, would be obtained; and, if sufficient regularity were exhibited, some general laws might be arrived at. With this view a considerable number of experiments have been examined, and among them, some which were made expressly for the purpose; but as the latter only serve to confirm the results derived from other well-known experiments, already published, it will be simpler to refer to these, in stating the conclusions arrived at, and the ideas which have been elicited during this examination.

The mathematical theory of elasticity, which is stated in the most general manner by Poisson, and in more detail by Navier, is assumed; and the formulæ used in the examination, with the manner in which they were derived, are stated at length, in an Appendix to this Paper.[1] By finding for each experimental beam, the centre of gravity of the area of cross section, through which, according to the theory, the neutral axis passes;[2] and calculating the moment of the forces with respect to this axis, somewhat in the manner employed by Mr. Eaton Hodgkinson for the large

[1] This Appendix may be consulted at the Institution.

[2] *Vide* Poisson, Traité de Mécanique, vol. i., p. 615, and Navier, Application de la Mécanique, p. 42, No. 78.

tubes of the Britannia Bridge, the application of the formulæ to the experiments was easily made.

The experiments on timber, (although confirmatory of the conclusions here arrived at) being very few in number, the observations have been restricted entirely to wrought and cast iron.

The first constant obtained, was the weight per square inch of the modulus of elasticity,[1] and this, when deduced from the transverse strain, was taken from the deflections produced by small weights, and in all cases where the beam, or bar, was very little strained. For wrought iron, the most comparable experiments, from having been made on the same quality of iron, are those detailed in the Iron Commissioners' Report.[2] The experiments on the transverse strain give from 12,200 to 12,750 tons, and those on the extension of bars from 12,200 to 12,900 tons per square inch. Other experiments on the transverse strain give from 9,000 to 14,000 tons per square inch. In like manner, for cast iron, the most comparable experiments, because made on the same kinds of iron, are those detailed in the same Report. The results are given in the following table, in which the bracketed figures refer to the page in the Report, from which the result is deduced. The last result for Gartsherrie iron, from transverse strain, is taken from a table in Tredgold on cast iron.[3]

TABLE.—Values of the modulus of elasticity of cast iron, in tons per square inch, derived from experiments on the tensile, compressive, and transverse strains.

Names of Irons.	From Tension.	From Compression.	From Transverse Strain.
Low Moor	6225 (31)	4940 (33)	5270 (33)
Blaenavon	6190 (33)	5700 (33)	6425 (33) to (39)
Gartsherrie	6500 (33)	6455 (33)	6210
Averages	6305	5698	5968

In examining other experiments on cast iron, given in the Appendix to this Paper, results were found, varying from 4,000 to 8,000 tons; and this great variation is worthy of notice, because Mr. W. H. Barlow, F. R. S., M. Inst. C. E., in some experiments on the neutral axis, recently laid before the Royal Society,[4] finds a result nearly agreeing with the higher number. The result, from this experiment, is however a little too high, since the line mea-

[1] *Vide* Young's Lectures, vol. i., Lecture 13.

[2] *Vide* "Report of the Commissioners appointed to inquire into the application of Iron to Railway Structures," pp. 39—50.

[3] *Vide* Tredgold on Cast Iron, vol. ii., p. 404.

[4] *Vide* Phil. Trans. for 1855. The account has been republished in the Civil Engineers' and Architects' Journal for January 1856.

sured became curved, while the measuring rod continued straight, and also the line measured was not equally strained throughout its length, the strain being a little less at the ends.

Another mode of arriving at the value of the modulus of elasticity, by means of the bending, or breaking weight of "long pillars," was also examined. The ratios of the lengths of the pillars to their diameters were taken as abscissæ, and the bending weights, by theory and experiment, as ordinates. The bending weights by theory, were obtained by assuming the weight of the modulus of elasticity per square inch, to be 10,000 tons for wrought iron, and 6,000 tons for cast iron.

It was thus found, that for the experiments on wrought-iron pillars,[1] the curve of theory agreed very well with the curve of observation, until the length became shorter than seventy times the thickness. The experiments examined, on cast-iron pillars, were those given in the second volume of Tredgold on cast-iron. The correspondence with theory was very good for those with the ends rounded, until the length became shorter than twenty times the diameter; and for those with the ends flat, until the length became shorter than fifty times the diameter. The hollow cylindrical pillars, with the ends rounded, gave, with the single exception of the short pillar in the last experiment, values for the modulus of elasticity ranging from 4,350 to 6,680 tons.[2] In the experiment on the neutral axis, by Mr. W. H. Barlow, although the mode of proof is very direct, and the result satisfactory, yet it only proves the point, in the case of a rectangular cross section. The correspondence shown above, between theory and experiment, and also in the Appendix, where many complex cases of cross section have been examined, seems to warrant the conclusion, that the theory is perfectly trustworthy when only small compressions and extensions are concerned.

Before proceeding further, it may be as well to offer a few remarks, on the fundamental assumptions usually made in the theory of the strength of materials.

The first assumption, that in a beam strained transversely, the extensions and contractions of the particles are proportional to their distances from the neutral axis, is tantamount to saying, that a series of points, which were all in a straight line, perpendicular to the length of the beam, before it became strained, still remain in a straight line, perpendicular to the curvature of the beam, after it becomes strained. Straight lines, drawn perpendicular to the length, on the sides of a rectangular beam of timber, remain, when examined by a hair stretched in the focus of a lens, to all appear-

[1] *Vide* Iron Commissioners' Report, pp. 139 et seq.
[2] These results are shown in greater detail in the Appendix.

ance straight, while the beam is strained transversely up to the breaking point; and in fact in a homogeneous material, it cannot be conceived how this can be otherwise, for there seems no reason why the line should become bent at any point to one side, rather than the other, and the above assumption therefore has somewhat of the character of a physical necessity.

The second assumption, that the extensions and compressions are proportional to the tensile and compressive forces, which is known as Hooke's law, and is expressed by the phrase "Ut tensio, sic vis," has been long ago remarked by Dr. T. Young,[1] to be "almost a necessary consequence of any primary law that can be imagined for the immediate actions of the particles." Dr. Robison also draws the probable conclusion,[2] that "when we observe the compression or dilatation proportional to the force employed, we may conclude that the compression or separation of the atoms is very small in comparison with their natural inactive distance." Viewing this matter, however, simply in the light of an experimental fact, it is no doubt the reason why, in the above investigation of the value of the modulus of elasticity, theory and experiment so well coincide.

The remaining assumption is, that, always supposing the law of "Ut tensio, sic vis," to hold good; whenever in a beam subjected to transverse strain, the tension, or compression on the outside particles, is the same as would be obtained, by direct experiment, on pulling asunder, or crushing, bars of the same material, the beam gives way. It will be worth while to examine this assumption a little more closely. It appears from experiment, that for large compressions and extensions, the above law ceases to apply.

With regard to the experiments on compression, it seems a little doubtful whether the true law has been arrived at, since the almost imperceptible bendings, or even bulgings, which the pillars must have sustained during compression, may have increased, to some slight extent, the values of the compressions above their true amounts; but, as they are the only recorded experiments on this subject, they are here assumed as expressing the true law.

It will be observed, that in cast iron, the law of Hooke does not differ widely from the truth, within the range of experiments; while in wrought iron, although the difference is great near the point of rupture, yet the curve of compression is similar in form to the curve of extension, the ordinates likewise being nearly equal in amount, and the true law may be roughly expressed by saying, that beyond a given amount of force, the same force

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[1] *Vide* Young's Lectures, vol. i., Lecture 49; see also proposition A in the article "Bridge," in the Encyclopædia Britannica.

[2] *Vide* Robison's Mechanical Philosophy, vol. i., p. 273.

corresponds to all compressions and extensions, this force being nearly the force of rupture, either by longitudinal compression, or extension; in other words, the force is scarcely altered by a large increase of the compression, or extension. The force on the outside particles, being deduced from formulæ, which assume the law of Hooke, it may be worth while to examine, what effect the above-mentioned deviation from this law would have. To simplify the consideration, the liberal supposition may be made, that the force is constant, and therefore equal to the force of rupture for all compressions, or extensions; that is, that the above roughly expressed law, not only holds good for all compressions and extensions above a certain amount, but for all compressions and extensions however small. From this investigation (MS. Appendix, Note A.) the Author thought it would be obvious, that the supposition of a constant force is different from the truth in one direction, while the law of Hooke is different from it in another, so that these two laws form limits, between which the truth always lies; in cast iron the latter law being more nearly approximated to. It is shown (MS. Appendix, Note B) that if the tension, or compression of the outside particles of a rectangular bar, when rupture takes place, is calculated from an experiment on the transverse strain, assuming the law of Hooke, the result will only require diminution in the ratio of 3 to 2, if the law instead were such, that the same force corresponded to all displacements. And if, instead of a rectangle, the beam had a tubular, or a double I section, wherein the bulk of the material is placed at a considerable distance from the neutral axis, the difference between the two laws is practically insensible; so that it is immaterial for these forms of section which law is assumed.

It appears, then, from the above considerations, that the results derived from experiments, by assuming the ordinary law, are slightly above the truth, the difference even in a rectangular section of wrought iron, being probably less than 20 per cent., and in cast iron still smaller, while in large box and in double I girders the difference is practically insensible.

The other constant obtained, was the value in tons per square inch, of the tension and compression of the outside particles, when the beam became ruptured by transverse strain. For wrought iron, the experiments on solid iron bars, are fewer than might be wished, and give results varying between $14\frac{1}{2}$ and $18\frac{1}{2}$ tons per square inch. In this material it may probably be the compressive, rather than the tensile force, which determines the fracture. The only experiments on direct compression of wrought iron, are those on the two bars,[1] where the one bar gave way under a strain of 14·5 tons, the other under 13·8 tons per square inch. The

[1] *Vide* Iron Commissioners' Report, p. 122.

quality of the iron is not stated, but it was probably soft. It ought to be remembered, that as wrought iron is manufactured from cast iron, and as between "wrought" and "cast" iron, there may be a considerable number of gradations, approaching to the one kind, or the other, according to the degree of manufacture; the better kinds of wrought iron may be able to sustain a greater tensile force, and the worse kinds a greater compressive force.

According to Mr. Eaton Hodgkinson's experiments, wrought iron may be defined as having its tensile to its compressive force, nearly in a ratio of equality; cast iron as having those forces in a ratio of about 1 to 6.

This being the case, it is worthy of consideration, whether in the plates of a large wrought-iron bridge, subjected to compression, a slightly inferior quality of iron might be used, not only as more economical, but as really better in itself.

On the whole, although the experiments are few, yet, bearing in mind that in good iron the compressive forces, and in inferior iron the tensile forces, are the weakest, and as such will determine the fracture; there appears every probability, that the ordinary theory may be applied, even up to the point of rupture, and the difference from the truth will be very slight. For riveted iron, the results from all the wrought-iron tubes in the above-mentioned Report, are stated in the Appendix. The following numbers are mean results:—

TABLE.—Values of the forces of the outside particles at the time of rupture, in tons per square inch.

Reference to Iron Commissioners' Report.	Description.	Compression of Top.	Tension of Bottom.
Page.		Tons.	Tons.
116	Cylindrical tubes. . .	13·3	13·3
116	Elliptical tubes . . .	16·5	16·5
117	Rectangular tubes . .	16·8	16·8
125	Ditto ditto . .	15·4	16·0
131	Ditto ditto . .	16·9	18 9
400	Large model tube . .	11·2	13·5

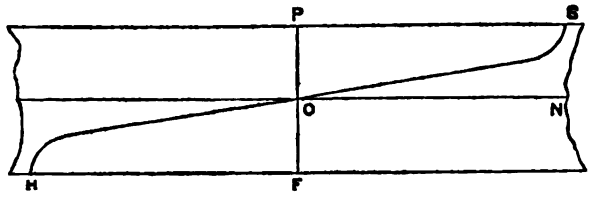
The three first results are taken from Mr. Eaton Hodgkinson's figures in the Report.

The results varied from 7·1 to 24·8 tons per square inch, but the lower numbers were apparently caused by using thin plates, for tubes of comparatively large diameter. If this be avoided, it appears that, to calculate the strength of wrought-iron tubes, from the formulæ given in the Appendix, it would not be safe to allow

more than about 15 tons per square inch for the breaking force on the outside particles.

When the experiments on cast iron are examined in this manner, the following fact becomes apparent. Experiments on small bars, broken transversely, give results of 20 tons, and even beyond, for the tension and compression of the outside particles, when the experiments are examined by the ordinary theory; and even if these results be diminished by 20 per cent., which it appears by the remarks previously made, will more than make up the difference caused by assuming the ordinary law, there is still a result of say 16 tons, while it appears by direct experiments on the tensile force of cast iron, that 7 or 8 tons is the utmost that it will bear. In regard to this subject, the hypothesis has been advanced, that the neutral axis shifts its position as the beam becomes strained, and that when rupture takes place, the neutral axis is "at, or above, the top of the beam."[1] It should, however, be remembered, that the position of the neutral axis is determined by this; that the sum of the compressive forces on one side of the axis, must be equal to the sum of the tensile forces on the other, and that, therefore, if there are tensions on one side of the axis, there must be an area out of which to get compressions sufficient to balance them on the other. The above hypothesis is, consequently, contradictory to the elementary principles of Mechanics. In Fig. 1, the amount of shifting of the neutral axis for a rectangular bar at the point of rupture, has been drawn by taking the true law of the compressions and extensions for wrought iron by experiment; and making the compressive forces on one side of the neutral axis, balance the tensile forces on the other.

Fig. 1.



If O N be the neutral axis, and P S the amount of tension at the outer surface P, F H, the amount of compression at the outer surface F, then since O N is the neutral axis, the curvilinear areas O H F and O S P are equal, and the shifting of the neutral axis is the amount by which O differs from the middle of P F. Be-

[1] Mr. W. H. Barlow, in the Paper already referred to, adverts to this hypothesis in these words.

cause these curves of tensile and compressive forces are somewhat similar, it follows that the shifting of the neutral axis for wrought, and, *à fortiori*, for cast iron, is very slight; therefore this cannot be the reason of the above discrepancy.

As evidence on this point in one material, viz., glass, the observations of Sir D. Brewster in passing polarised light through a piece of glass subjected to transverse strain, may be referred to.[1]

On these observations Sir J. Herschel remarks, that "Dr. Brewster developed seven orders of colours before the glass broke with the bending force applied,"[2] and therefore if the 'black fringe' in the middle had altered its shape, from the shifting of the neutral axis, there would have been an observation on such a circumstance; and the probability therefore is, that the shifting, if any, was too small to be observed. Dr. Robison[3] remarks, that in glass the tensile force is to the compressive, as 1 to 20 or 25. For a rectangular bar strained transversely in the above manner, it is easy to show, (MS. Appendix, Note C,) that the points of equal strain lie in hyperbolic curves, agreeing with the coloured lines in Sir D. Brewster's Experiment.

Mr. Barlow seems to think, that there is some lateral action of the particles tending to strengthen the beam, but it is not easy to see how there can be any lateral forces, which have not been already included in the compressive and tensile forces. No doubt each particle of the beam acts on every other particle within the sphere of its action, and, therefore, there are virtually forces acting in all directions round each point, but these forces are supposed to be all resolved into two sets; one set acting parallel to the length of the beam, and the other set at right angles to this length. The first set are the tensile and compressive forces, the second set have a resultant equal to zero, or mutually balance each other. As all the forces of the particles are, therefore, supposed to be included, there can be no other forces in operation.

In experiments on the direct tensile strength, it is assumed, that the outward force is uniformly distributed over the area of the bar —in other words, that the resultant of the external forces acting on the bar, passes through, and has the same direction with, the axis. This probably obtains in wrought iron, from its great extensibility before rupture—but in cast iron there is no such extensibility, and this point is to some extent doubtful. Moreover, it must not be forgotten, that if the force deviates from the axis of the bar, by so much as one-sixth of its diameter, it will break with only one-half of what it would do, if the force were coincident with the axis. If

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[1] *Vide* Phil. Trans. for 1816.
[2] *Vide* Encyclopædia Metropolitana, Light, Art. 1090.
[3] *Vide* Robison's Mechanical Philosophy, vol. i., p. 408.

a few experiments were made, in which the force deviated from the axis by certain large and measurable amounts, and then were made to approach the axis, until some law were obtained, which could be tested by theory, this point would be set at rest. Although the experiments of small cast-iron bars broken transversely give such high results, this is by no means the general character of the experiments on the transverse strain, when examined on the principles already stated.

The following Table shows the mean results from the several classes of experiments examined, and also a few single results obtained from large beams. The means of the compressive forces have not been inserted, but only the means of the tensile forces; as it is probable the beams all broke by tension.

TABLE.—Values of the forces on the outside particles at the time of rupture in tons per square inch.

Reference.[1]	Description.	Tension of Bottom.
		Tons per Square Inch.
R., page 390 . .	Mr. Hosking's experiments for Mr. R. Stephenson on 1-inch bars	20·8
Ditto 84 . .	Mr. Eaton Hodgkinson's experiments on Blaenavon bars, 1 inch by 1 inch	15·4
Ditto 78 . .	Ditto ditto 2 inches by 2 inches .	11·5
Ditto 76 . .	Ditto ditto 3 inches by 3 inches .	11·8
Ditto 251 . .	Captain James's experiments on bars 1 inch by 1 inch	18·7
Ditto 253 . .	Ditto 2 inches by 2 inches . .	17·1
Ditto 253 . .	Ditto 3 inches by 3 inches . .	14·7
Tr., page 462 .	Mr. F. Bramah's experiments on small T bars	17·6
J., page 9 . .	Mr. W. H. Barlow's experiments on small open girders.	14·8
Tr., p. 381 & 415	Mr. Hodgkinson's experiments on small T girders	12·5
Ditto 424 .	Ditto ditto on I girders, Table 1 . .	10·2
Ditto 432 .	Ditto ditto Table 2 . .	10·5
Ditto 436 .	Ditto ditto Table 3, Section L. . .	11·1
Ditto 466 .	Mr. T. Cubitt's experiments on I girders. .	10·5

SINGLE EXPERIMENTS ON LARGE BEAMS.

Tr., page 454 .	Mr. March's experiment	9·7
Ditto 456 .	Mr. Gooch's ditto	8·9
Ditto 459 .	Mr. Hodgkinson's ditto	8·3
R., page 94 .	Mr. Hodgkinson's and Lieut. Galton's ditto .	7·4
Ditto 379 .	Mr. P. W. Barlow's experiment on corrugated girder	8·9
Ditto 380 .	Ditto on trough girder.	6·0

[1] (R.) means Iron Commissioners Report; (Tr.) Tredgold on Cast Iron, vol. 2; (J.) Civil Engineers' Journal, vol. 19.

In these results, there appears a diminution as the size of the beams increases. Beams 3 inches by 3 inches, as compared with those of 1 inch by 1 inch, show a falling off of strength, to the extent of about 4 tons per square inch. The particular results from both Mr. Eaton Hodgkinson's and Mr. Cubitt's tables are unexpectedly regular, and show results of about 10 tons per square inch. The mean of Mr. Cubitt's experiments is taken from the sound beams; if the unsound ones were included, the mean would be 9·6 tons. For Mr. Barlow's corrugated beam, there appears some ground for thinking, that the result may be a little too high. The last result, for the trough girder, is the lowest of all, and in the calculation the weight has been taken as acting in the middle, although this is not directly stated. This girder may have broken by compression, as the compressive force was 22·4 tons per square inch, and the upright ribs being very thin, the top parts of them may have been somewhat in the state of a "long pillar," and have given way by bending sideways. In beams of double I section, some part of the weakness may perhaps be owing to the compressing of the moulding sand, by the flanges of the metal, during its shrinkage in cooling, which may have caused an initial strain: or the falling off in strength may be caused, in some way or other by the cooling of the metal. These are points worthy of further investigation, since, whatever may be the cause, the above are the results for large beams. It appears, therefore, that the breaking weight of tolerably large girders, may be calculated to considerable accuracy; using 7 or 8 tons per square inch, as the force of tension on the outside particles, when rupture takes place.

In conclusion, seeing that experiments are frequently made, and empirical formulæ deduced from them, which, although they may be made to fit the particular experiments, are yet dangerous, if applied to others; it is hoped that attention has been directed to the true principles (because founded on mechanical laws) by which all experiments ought to be examined, and that the following conclusions have been established.

1st. That in experiments where the materials are but slightly strained, theory and experiment coincide.

2nd. That where the ordinary theory is applied to the rupture of beams, and especially large beams, of wrought iron, theory and experiment practically coincide.

3rd. That there appears to be no good reason for supposing that the neutral axis shifts its position to any extent worth noticing, even up to the time of fracture.

4th. That in cast iron, although theory and experiment seem to differ, when the transverse strength of small bars is compared with the direct tensile strength, assuming the

latter to be correctly stated at 7, or 8 tons per square inch, yet when the transverse strength of large girders, is compared with the direct tensile strength, the coincidence of theory and experiment is nearly exact.

5th. That the ordinary theory of the strength of materials is more trustworthy than is generally supposed.

The Paper is accompanied by an Appendix, giving the calculations, and, by diagrams, showing the forms of the beams investigated.

[Mr. PETER W. BARLOW

Mr. PETER W. BARLOW said, that valuable as the calculations, presented by the Author of the Paper, might be, he yet doubted the correctness of some of the conclusions which had been arrived at. The expression "the weight per square inch of the modulus," was hardly a correct one, for the modulus itself was imponderable, —being only a term,—the weight really representing the modulus. The amount of extension in length of a cubic inch of metal, by the application of a weight of one ton, would represent the modulus expressed by the Author. It had been found by experiment, that, in cast iron, 8 tons produced an extension of about $\frac{1}{500}$ of the length; therefore the extension of its own length per inch, would amount to 4,000 tons. In wrought iron it would amount to about 12,000 tons. It had been asserted, that Mr. W. H. Barlow, in the account of some experiments on the neutral axis of beams, laid before the Royal Society,[1] had stated the modulus of elasticity of cast iron to be about 8,000 tons. This was not correct, as in the calculations referred to, the modulus of elasticity had not been estimated at all.

The amount of strain on the upper fibres of a parallel rectangular beam, without large top and bottom flanges, might be readily calculated. With a load in the centre, it was capable of bearing more than double what was given by the ordinary theory, in which the Author agreed. This arose from a new kind of resistance coming into operation, which was not allowed for in the rule. In a girder with solid sides, the increased strength was due, he believed, to the resistance to motion and lateral disturbance of the atoms, or particles. In a lattice, or triangular girder, the calculations from theory agreed with the results of experiments.

If, when the parallel rectangular beam was deflected by a load in the middle, the upper particles of the beam being compressed, and the lower ones extended, it was cut along the middle, in the line of the neutral axis, the deflection would be increased by the separation of the particles, or atoms, and the upper portion of the beam would move, or slide upon the lower portion. The resistance of the atoms to move laterally, which prevented this increased deflection when the beam was whole, represented the resistance pointed out by Mr. W. H. Barlow, in the experiments before referred to.

The Author, however, had arrived at the conclusion, that no such resistance occurred, which Mr. P. W. Barlow thought, was likely to lead to error, because engineers could not always adopt the shape of girder they most approved; so that it was important to ascertain, in all cases, the extent of this resistance.

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[1] *Vide* Phil. Trans. for 1855, and quoted in the Civil Engineer and Architect's Journal, for January 1856.

With reference to the corrugated and trough girders, which had likewise been alluded to, Mr. Barlow might explain that they had been extensively used by him on the North Kent and other lines, for bridges over the line of railway, with the object of bringing the level of the road and the under side of the girder as near together as possible. Previously, the space between the iron girders, composing the platform of the bridge, had been formed of baulks of timber, slabs of slate, or stone, and sometimes of brick arches, which did not in any way add to the strength of the girder. In this case, on the contrary, the whole of the metal in the platform added to the strength of the girder, as well as supported the roadway; and although the girder might not be of the best form, theoretically, yet, he believed, cases would constantly occur in which it could be advantageously employed.

Mr. DOYNE remarked, that there was little to be said on the practical part of this question, which had not already been previously laid before the Institution. There was scarcely any limit to the mathematical formulæ that might be constructed; but, he thought the investigation, so far as it led to practical rules for the use of Engineers, was nearly exhausted. In the discussion upon Mr. Barton's Paper on the Boyne Viaduct,[1] Mr. Doyne had given a practical rule,[2] which he had arranged for the calculation of the strength of cast-iron beams under transverse strain. This rule was then intended to apply to beams of the double I pattern, however variable the proportions of the top, bottom, or middle web might be. It was a modification of Mr. Eaton Hodgkinson's rule for beams of that form, with the middle web as thin as possible, which that gentleman considered, theoretically, to be the most economical. He had tested the correctness of this rule, by applying it to all the forms of cast-iron beams with which he was acquainted, including those alluded to by the Author, and those named in Mr. Hodgkinson's work, besides some hundreds of experiments made by himself. He commenced with the extreme cases of square bars, then with flat plates with a small rib along the centre, and then he went through all the forms of T and double I girders, and found the rule to be practically correct for all forms.

The principle upon which that rule had been constructed was, that the line upon the section of the beam, at which the two opposite forces of tension and compression met, (commonly called the neutral line, or axis,) was one which divided the area of the section into quantities, which were in the inverse ratio of their power to resist the forces to which they were exposed, at the moment of rupture. For cast-iron beams, supported at the ends

[1] *Vide* Min. Proc. Inst. C.E., vol. xiv., p. 452.
[2] Ibid. p. 460.

and loaded in the centre, this line would be one drawn horizontally across the section of the beam, leaving one-eighth of the area above, and seven-eighths below it; on the assumption that the metal would resist compressive and tensile strains in the proportion of one to seven. The strength of the beam would then be found, by assuming, in the calculation, the depth of the beam to be the distance between the centres of gravity of the areas above and below this line; and these areas to be respectively in compression and tension, and then applying the ordinary rule for the strength of beams.

The area of the lower web (a)
× The depth of the beam (d)
÷ The length between the supports (l)
× The constant (7 × 4) 28 (c)
= The breaking weight in tons at the centre (W)

(a) being the area of the section below the "neutral line."
(d) the depth or distance between the centres of gravity of the two parts of the section.
(c) a constant assuming 7 tons to be the ultimate tensile strength of cast-iron.

A rule constructed on the same principles could be applied equally well to wrought iron. In this case, the compressive and tensile resistances were more nearly equal, or in the ratio of about 18 to 20. He believed this rule would be found to apply to wood, or to any other material by which it could be fairly tested.

He considered, that the mathematical reasonings upon the position of the "neutral line," under a small amount of strain, would probably never be brought to the test of experiment, as there was as yet no means of measuring the result upon all the particles, until the moment of fracture. Nor did he think such investigations were of much importance to Engineers, who were now in possession of all the principles which practically affected the application of iron to engineering purposes.

Mr. HEPPEL said, this Paper, like the one which he had the honour of laying before the Institution on a similar subject last Session,[1] was scarcely capable of being discussed. It was satisfactory to learn, that the differences from what was called the ordinary theory, were only great in some forms of beams, not very generally used, whilst in those beams which Engineers most frequently employed, they could not commit any serious error, in taking the ordinary laws as the basis of their calculations. He had read Mr. W. H. Barlow's Paper with some attention. The experiments there detailed were applicable rather to rectangular

[1] *Vide* Min. Proc. Inst. C.E., vol. xv., p. 155.

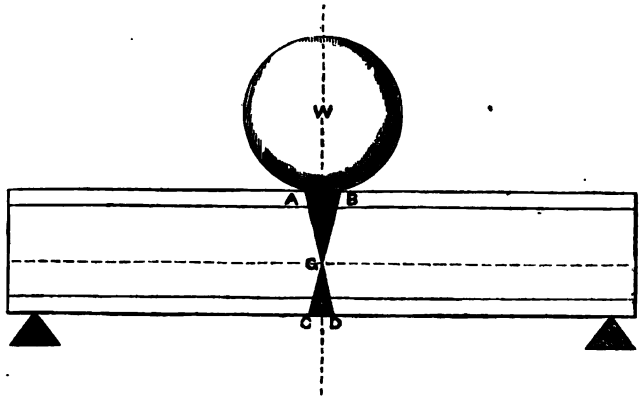
beams than to those now alluded to. His impression was, that Mr. W. H. Barlow showed clearly, that there must be some other force in action in the case of rectangular beams, beyond that which was calculated by the distance from the neutral axis. He thought it reasonable to suppose, that the deviation might become of less importance, as the middle portion in a beam became a less part of the whole section of the beam; and this agreed with what had been said in his own Paper, that the middle part of the beam, besides contributing its proportion to the compressive and tensile forces, performed also another office, that of transmitting the diagonal forces: and the particles in the neighbourhood of the neutral axis were especially occupied in bringing the tensile into opposition with the compressive forces. He thought, with Mr. Barlow, that there were other forces at work, besides those of compression and tension; and in his Paper he had attempted to obtain the resultant forces arising from the combination of the horizontal forces with the forces that corresponded to those sustained by the diagonal bar of a lattice beam. He thought the Paper was well worthy of study; and if it was established that the law they had been in the habit of acting upon was trustworthy, the Author had rendered the profession good service.

Mr. E. A. COWPER remarked, that Mr. W. H. Barlow in his Paper, supposed a plain solid cast-iron beam to be divided into horizontal laminæ, and that as the "sum of the forces" would not account for the whole of the strength, he had assumed that there was an additional force in operation, which had not before been calculated, obtained by the mutual adhesion of their laminæ, thus enabling them to help one another. Now Mr. Cowper differed from that theory, because if all the laminæ were in extreme tension and compression, they could do no more duty. He thought it could be traced to other causes. All iron was more, or less ductile; he had produced an extension of $5\frac{5}{8}$ inches in a heavy bar of wrought iron of 7 feet 6 inches long, without causing any diminution of strength, and all plain cast iron solid beams might be deflected and "set," to a considerable extent, without breaking; thus proving, that the ductility practically exercised great influence on the strength of a bar; for "the bar would take a considerably greater weight to make it take a set, than it would if a set were avoided." If the neutral axis was in the centre, and the iron had 10 tons per square inch on the bottom laminæ; a lamina half way between the neutral axis and the bottom should have 5 tons per square inch on it, on the ordinary rule of the "sum of the forces." Now, he should say it was more like 7 tons, because the laminæ got more and more strain on them, as the bottom lamina stretched, so that there were more than the top and bottom laminæ doing full duty, or nearly full duty. They

could, on this supposition, account for the extreme breaking weight of a solid beam, but by no other theory that he was aware of.

Mr. PHIPPS agreed in the opinion, that the neutral axis was always situated at the centre of gravity of the section of cast-iron beams. As a consequence of this, if a beam on being deflected was supposed to have a certain amount of angular motion about the neutral axis, G, (Fig. 2,) at any given point in the length of the beam, the cubic contents of the material included within the angular lines G A B, situated above the neutral axis, would always be equal to the cubic contents of the angular portion G C D below that point. He also agreed, generally, in the explanation of the singular fact, first, he believed pointed out by Mr. W. H. Barlow, of the greater apparent strength of cohesion of iron when situated in the exterior portions of the cross section of a beam exposed to transverse strain, over a like area torn asunder by direct tension.

Fig. 2.



The theory of Galileo, referred to in the first edition of Barlow's Treatise on the Strength of Timber,[1] seemed rather to favour the facts referred to in Mr. W. H. Barlow's recent Paper, inasmuch as Galileo's theory was, that each of the extended fibres in a deflected beam, instead of exerting a force according to Hooke's law, in proportion to its distance from the neutral axis, were in fact all strained alike. This would have the effect of making all the middle portions of a rectangular beam do more work than was generally attributed to them, and hence that the outer fibres did less.

[1] *Vide* "An Essay on the Strength and Stress of Timber, founded on Experiments," &c. By P. Barlow. 8vo. Plates. Lond. 1817.

Mr. R. SHEPPARD, through the SECRETARY, submitted to the notice of the Meeting, the following experiment.

Having procured a beam of lead, 24 inches long and 1 inch square, he divided the face by fine vertical lines into squares of 1 inch: the top and bottom of the beam were similarly divided by horizontal transverse lines. A load being then applied, sufficient to bend the beam considerably, the vertical lines inclined inwards at the top, and diverged at the bottom. As nearly as he could ascertain by an ordinary plotting scale, the distance between the lines on a mean of six squares, was changed from 1 inch throughout, to 0·95 at the top, and 1·06 at the bottom; and the transverse section, instead of being uniformly 1 inch, was 1·04 at the top, and 0·98 at the bottom. Such a displacement of the particles having taken place, a question for future consideration arose, as to whether any change had occurred, in the specific gravity of any portion of the beam. But it was evident, that some change must have taken place in the length of the vertical, or diagonal lines; either the vertical lines must be compressed, or the diagonal lines be extended. His experiment was, unfortunately, on too small a scale to enable him to settle this point accurately, but he was induced to believe, that the vertical lines were contracted.

If the experiment had not been already made, and the fact ascertained, he thought it might be the means of inducing a trial of the experiment on a larger scale, and thus deciding the point, the importance of which was sufficiently obvious.

No. 953.—"Some account of the recently-discovered Deposits of Iron-Ore at the foot of the Himalayas, in Kumaon, Northern India." By WILLIAM SOWERBY, Assoc. Inst. C.E.

THESE deposits are found in the lower range of hills, called the Bhabur, at a general elevation of about 500 feet above the adjacent plains; and they are more or less continuous from the river Sada, on the confines of Nepal, to the river Ganges, a few miles above the head of the Grand Ganges Canal, at Hurdwar, thus extending over a length of about 150 miles.

There are six different superposed beds of iron-ore, of varying thickness and quality. The lowest bed is a rich red ore associated with clay, and its thickness is, in many places, upwards of 50 feet; it contains an average of at least 50 per cent. of metallic iron. The following is an analysis of these ores:—

Water and Carbonic Acid	2·00
Earthy matter	22·40
Arsenic	0·91
Lime	2·60
Peroxide of Iron	73·50
	101·41
Excess.	1·41
	100·00

Metallic Iron 50·96 per cent.

The other beds are chiefly compact brown clay iron-ore, about 15 to 20 feet in thickness, containing about 40 per cent. of metal. There are also yellow hydrates and silicious iron ores, in beds of less thickness and of a poor quality. Masses of the richest iron-ore, many tons in weight, are found lying on the slopes of the hills, and the beds are, in many places, exposed in the high escarpments and the deep ravines.

The rocks containing the mineral beds are micaceous sandstones, resembling those of a coal formation; thin seams of lignitic and slightly bituminous coal have been found outcropping near these spots; and mountain limestone of excellent quality for flux, is found in the adjacent hills.

The district in which the iron-ore is found, is a dense primeval forest of saul, huldoo, kya, jamin, and other hard woods, in inexhaustible quantity, and peculiarly suitable for making charcoal. The number of streams and rivers issuing from the hills would afford ample water power for any amount of machinery.

The Government of India decided on intrusting to the Author,

the erection of a small experimental blast furnace, at Dehchowree, during the cold season of 1855-56, and the specimens of iron now produced are the result of these experiments, which were so conclusive and satisfactory, as to decide the question of the extension of the works.

The interior of the hills also contains considerable deposits of rich hematite, specular, and magnetic iron ores, with copper, galena, and other minerals.

Views of the locality and of the work erected accompanied the Paper.[1]

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[1] The following are the results of some further assays, and also of experiments on the quality of the iron manufactured at Dehchowree :—

Messrs. Johnson and Matthey, assayers, report that "the twelve specimens of iron ore have been most carefully assayed for Mr. W. Sowerby, and have been found to produce the following per centage of good pig iron :—

No. 1. Ganges	55¾	No. 7. Kosilla	45½
2. Ganges	47¼	8. Ditto	29½
3. Mundil	8	9. Ditto	28
4. Kotdwarra	34½	10. Kitcheree	17½
5. Kotree	25	11. Dubka	21
6. Ramgunga	30	12. Boer	6¼"

Specimens Nos. 1 and 2 are from the eastern banks of the Ganges, a little above Hurdwar, a fine large mass from which locality was deposited at the Roorkee Works.

The neighbourhood of Kotdwarra, 25 miles east of the Ganges, has been pointed out as a good locality for establishing iron works, from the abundance of iron-ore in that locality, and its proximity to Roorkee. It is satisfactory to find, that the assays (Nos. 4 and 5) show a good per centage of iron; better, indeed, than the appearance of the specimens seemed to indicate.

The whole of the specimens were taken up indiscriminately from the surface, and labelled at the time. As they were from the exposed outcrop, they could hardly be expected to be very rich. The average per centage of iron in all the specimens, it will be seen, is 29½. The specimens which exhibited a low per centage were taken from the upper series of narrow beds, described as being fit only for mixing with and reducing the richer ores.

The following Table gives the results of some experiments made at the Royal Arsenal, Woolwich, on a pig of iron manufactured at the blast furnace erected at Dehchowree in Northern India, in 1855-56.

No.	No. of times the Iron had been remelted.	Description of Strain.	Dimensions.	Breaking Weight in lbs.	Deflection.	Remarks.
1	Second	Transverse	Bar 24 inches long, 20 inches between bearings, and 1·5 inch square	5,100	·215	A flaw was found in the upper, or compression side.
2	Third	Tensile	Round ingot, 1·318 inch in diameter	15,500	..	Small flaw in centre of ingot.
3	Second	Tensile	Round ingot, 1·318 inch in diameter	29,000	..	21,261 lbs, or 9 tons 9 cwt. 3 qr. 11 lbs. per sq. inch.
4	Third	Tensile	Round ingot, 1·318 inch in diameter	23,800		
5	Second	Tensile	Round ingot, 1·318 inch in diameter	27,800	..	Small flaw in side.
6	Second	Crushing	Round ingot, ·8 inch in diameter and ·6 inch in depth	33,500	..	By the American method = 56·9 tons per cubic inch.
7	Second	Specific gravity	..	7·092		

Mr. SOWERBY directed attention to some specimens of coal, iron, copper, galena, &c., discovered by him in South Eastern Africa. The coal beds were in the territory of Natal, and were traced from the sea-coast to the Kathlamba Mounts, a distance of about 150 miles; they varied in thickness from a few inches to 14 feet at the outcrop. Iron, copper, &c., were also found in great abundance and variety, in different districts of the country.

The pig of iron, after being drawn from the furnace, had been re-cast on the spot, and it was again re-melted at Woolwich, into a bar 24 inches long and 1·5 inch square, for testing the transverse strength, and the remainder was cast into ingots for proving its tensile strength and specific gravity.

The first experiment shows, by the deflection of ·215 of an inch, that the iron possesses considerable elasticity in its cast state, and is equal to the best cold blast (C. B.) English iron. It is, therefore, well adapted for resisting heavy loads passing over it without breaking.

According to the formula of Mr. Eaton Hodgkinson, F.R.S., that

$$\frac{4{\cdot}5 \times db^2 S}{l} = \text{breaking weight},$$

where b is the breadth in inches,
d is the depth in inches,
l is the distance between supports in feet,
and S is the *constant* or mean breaking weight (which for cold blast iron is 456·9 lbs.).

$$\text{we have } \frac{\overset{\text{ft.}}{4{\cdot}5} \times \overset{\text{in.}}{1{\cdot}5} \times \overset{\text{in.}}{1{\cdot}5}^2 \times \overset{\text{lbs.}}{456{\cdot}9}}{1{\cdot}6666 \text{ ft.}} = 4163 \text{ lbs.}$$

That is, 4,163 lbs. would be the calculated breaking weight of such a bar, whereas it required 5,100 lbs., or 937 lbs. in excess of the average, to break the Kumaon iron, which is, therefore, 23 per cent. stronger than the average of 22 samples of English C. B. iron.

Reducing this to a bar of one inch in length, breadth and depth, the ordinary constant, or breaking weight for which is 11 tons, gives 13·5 tons, nearly, as the constant for the Indian iron. And if allowance be made for the flaw in the casting, the constant would then be about 15 tons, or 36 per cent. above the average strength of the best C. B. English iron.

The tensile strength, as shown by No. 3 experiment, was 21,261 lbs., or 9 tons 9 cwt. 3 qrs. 11 lbs. per square inch; whilst the average tensile strength of English cast iron is only 17,628 lbs. or 7 tons 17 cwt. 1 qr. 16 lbs. per square inch; the excess being 3,633 lbs., or upwards of 20 per cent. in favour of the Kumaon iron.

Its power to resist compression is shown by experiment No. 6, which was made upon a cylindrical piece of iron of small dimensions, according to the American method. This gives 56·9 tons per cube inch, whilst the result given by Mr. W. Fairbairn, F.R.S., is 43·6 tons per square inch, so that the Kumaon iron is 30 per cent. above the average.

No. 7 experiment shows the specific gravity as 7·092. The average twenty-four specimens of English C. B. iron given by Mr. Hodgkinson is 7·082. The Kumaon iron is, therefore, ·010 higher than the average.

From these experiments it is obvious, that the Kumaon iron is, from its extreme elasticity, its transverse and its tensile strength, well adapted for making railway bars, and all other kinds of railway iron. From its high specific gravity, its resistance to a crushing force, and close structure, it is equally well suited for making shot and shell.

The Government have recently decided upon carrying on the works upon a large scale, under the superintendence of the Author.—W. S. August, 1857.

ANNUAL GENERAL MEETING.

December 16, 1856.

GEORGE P. BIDDER, Vice-President,
in the Chair.

MESSRS. T. R. Crampton, G. Donaldson, and R. Garrett, were requested to act as Scrutineers of the Ballot, for the election of the President, Vice-Presidents, and other Members and Associates of Council.

The list of the attendances of the Members of Council for the past year was read, and the Ballot was commenced; the balloting papers being sent for examination, at intervals of fifteen minutes, in order to expedite the labours of the Scrutineers.

The Annual Report of the Council, on the proceedings of the Institution during the past year, was read.

Resolved,—That the Report of the Council be received and approved; and that it be referred to the Council, to be printed and circulated with the Minutes of Proceedings, in the usual manner.

The Telford Medals and Premiums, and the Council Premiums which had been awarded, were presented.

Resolved,—That the thanks of the Meeting are due, and are presented to Messrs. Grantham and Appold, for the readiness with which they undertook the office of Auditors of Accounts, and for the clear balance-sheet they have laid before the Meeting; and that Messrs. Appold and Doull be requested to undertake the office of Auditors of Accounts for the ensuing year.

Resolved,—That the thanks of the Institution are justly due, and are presented to the Vice-Presidents, and other Members of the Council, for their co-operation with the President, their constant attendance at the Meetings, and their zeal on behalf of the Institution.

Mr. Bidder, V. P., returned thanks.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Robert Stephenson, M. P., President, for his strenuous efforts in the interests of the Institution, for his attention to the duties of his office, and for the urbanity he has at all times displayed in the Chair.

Mr. BIDDER, V. P., in returning thanks on behalf of Mr. R. Stephenson, President, regretted equally his absence and the cause of it,—a journey for the restoration of his health injured by almost uninterrupted devotion to professional avocations, during a long period of the most eventful epoch of the engineering history of this country. He could assure the Members, that Mr. Stephenson's interest in the welfare of the Institution was unabated, and that if he was again elected to preside over them, he would neither spare time, labour, nor expense to advance the prosperity of the Society.

Resolved unanimously,—That the cordial thanks of the Meeting be given to Mr. Charles Manby, the Secretary, for his constant zeal and attention to the interests of the Institution, the ability displayed by him in the execution of his duties, and his attention to the individual wishes of the Members.

Mr. BIDDER, V. P., in communicating to Mr. Manby, Secretary, the resolution of the Meeting, said that a vote of thanks had never been more deservedly proposed, nor more unanimously carried. No one, perhaps, could judge better than himself the value of the services rendered by Mr. Manby, and he would embrace the opportunity of alluding to a circumstance, in connexion with himself, which exemplified the nature of a portion of those services.

The Members were aware, that during the last session he had undertaken to deliver two lectures upon "Mental Calculation," a subject considered peculiarly his own, and one with which few were familiar. It was impossible to convey to the Meeting, an adequate idea of the labour required to reduce the substance of the lectures into a form for printing, in the 'Minutes of Proceedings,' and but for the invaluable assistance afforded by his friend, Mr. Manby, he could never have succeeded to the extent that he had done. It would be difficult to describe the time and patience bestowed upon the work, not only during the period when Mr. Bidder occupied the attention of the Institution, but subsequently, in the preparation of the lectures for publication; at all times Mr. Manby's attention had been unremitting, and whatever time was required had been devoted in the most free, frank and liberal manner; and he repeated that but for this assistance his efforts in bringing the subject before the Institution would not have been so successful, nor could the lectures have been reduced to a form for publication; personally therefore he felt under very great

obligation to their mutual friend, Mr. Manby, to whom he had the greatest possible pleasure in communicating the resolution of the Meeting, especially as that was the only honorary reward he now received for his valuable labours on behalf of the Society.

Mr. MANBY, Secretary, in returning thanks, said he was so accustomed to thank the Members at each Annual Meeting, for the same kind expression of their confidence, that he was at a loss what to say, but he would again assure them, that he felt their kindness deeply on this as on all similar occasions.

Mr. Bidder had alluded to a peculiarly interesting event, and had kindly endeavoured to impress upon them the value of the assistance rendered in bringing those unique lectures before the Meetings, and in preparing them for publication. He assured them, that the aid he had been able to render had been over-rated by the kindly feelings of his friend; it was true that the assistance had been most willingly given, but thus far it was not any exception from the general rule, as he believed it to be one of the principal duties of the Secretary to co-operate in the production of Papers to be read at the Meetings. In this peculiar case, however, it was a great privilege to be permitted to aid in laying before the world so masterly an explanation of the intricate operations of the human mind. At the expiration of the task he was more than ever impressed with the remarkable analytical power of mind, which had enabled Mr. Bidder to obtain such a mastery over the science of numbers; and, in spite of the pride he felt in numbering so able a man amidst the body of Civil Engineers, he could not help feeling regret that Mr. Bidder had not been called to take a position, in the political, or financial world, where those great talents would have had a still wider field of action.

With respect to his own general services, they were ever at their command, whenever, or however they might be considered beneficial to the Institution, or to the individual Members. He had watched the Institution for a great number of years, even from the time of the election of the first President, and although he had now ceased to be its paid Officer, he should still feel the same interest in it, as he believed it to be one of the most useful Societies in the Metropolis, and it only required the individual and united exertions of its Members, to become even still more useful than it had hitherto been.

As regarded Mr. Forrest, the present Assistant Secretary, he felt, when the Council did him the honour of asking his opinion, that a better selection could not have been made. For the last fourteen years Mr. Forrest had been familiar with the proceedings of the Institution, and, as his pupil, had been trained with the intention of being permanently connected with it. It had not been anticipated that there would so soon have been an opening,

and therefore Mr. Forrest's services had for a time been transferred to another Society, where an opportunity was afforded of acquiring information of another kind, which, it might be anticipated, would render him still more useful. He would ask for Mr. Forrest the same kind confidence they had reposed in him, and felt confident they would find him a valuable officer.

The Ballot having been open more than an hour, the Scrutineers, after examining the papers, announced that the following gentlemen were duly elected to fill the several offices in the Council for the ensuing year:—

President,

ROBERT STEPHENSON, M.P., F.R.S.

Vice-Presidents,

George P. Bidder.	John Hawkshaw, F.R.S.
Isambard K. Brunel, F.R.S.	Joseph Locke, M.P., F.R.S.

Other Members of Council.

Members,

Wiliam G. Armstrong.	Thomas Hawksley.
Joseph Cubitt.	John R. M'Clean.
John E. Errington.	J. Scott Russell, F.R.S.
John Fowler.	Joseph Whitworth.
Charles H. Gregory.	Nicholas Wood.

Associates,

Robert W. Kennard.	Sir Macdonald Stephenson.

Resolved,—That the thanks of the Meeting be given to Messrs. Crampton, Donaldson, and Garrett, the Scrutineers, for the promptitude and efficiency with which they have performed the duties of their office, and that the ballot-papers be destroyed.

ANNUAL REPORT.

SESSION 1856-57.

SINCE the Council presented their last Report to the general body, that political tranquillity which was so much desired, has been restored, but the monetary crisis consequent upon the large public expenditure, occasioned by a state of warfare, has retarded the resumption of works of public and private enterprise.

The present Report may therefore be almost entirely restricted to noticing the proceedings within the walls of the Institution.

Exception may, however, be made in favour of a few foreign works in progress. Among these may be mentioned, the successful opening and the extension of the East Indian Railway, under our late distinguished member, Mr. Rendel. In connexion with this subject it should be stated, that the honour of knighthood has been conferred upon our Associate Member, Mr. Macdonald Stephenson, who originally proposed, and has so triumphantly carried out, the first portions of the vast network of railways, which is destined to work such a revolution in the Indian empire. A similar distinction was conferred, at the same time, upon Dr. W. B. O'Shaughnessy, the energetic projector and successful constructor of a system of electric telegraphs, extending over nearly four thousand miles, chiefly through the dense jungle, over the vast plains, and beneath the wide rivers of India.

The Indian Peninsular Railway, constructing by Mr. James Berkley, (M. Inst. C. E.,) under the direction of Mr. R. Stephenson, M.P., our President, has now about one hundred miles opened, and the great work of extension up to Sholapoor, and through the Bhore Ghaut, is fast progressing; whilst the execution of the north-eastern extension across the Thull Ghaut, towards Nagpore, and Jubbulpore, and the Berar cottonfields, will very soon be commenced.

The Madras, the Bombay and Baroda, and the Scinde Railways, are being vigorously prosecuted, and several other lines are projected, among which is that from Seleucia, on the Mediterranean, to Jabr Castle, on the Euphrates, which river it is proposed to navigate by means of steam-vessels, of shallow draught of water. This last project has been intrusted to our Member, Sir John Macneill. Since the kingdom of Oude has become a part of the British possessions, arrangements have been made for affording it the benefit of participation in the railway system, which will be commenced by the construction of a line of fifty miles in length between Cawnpore and Lucknow, with branches to the most important districts, and to connect it with the East Indian Railway.

Other lines are also proposed for Gorruckpore, Tirhoot, and Purneah, all contributing to the completion of the internal communications of India.

The Pernambuco Railway, in the prosecution of which our late Member, Mr. M. A. Borthwick (M. Inst. C.E.), recently lost his life, has been placed in the charge of Mr. W. M. Peniston, M. Inst. C.E., and is making satisfactory progress.

The Dom Pedro II. Railway, starting from Rio de Janeiro, and passing up the 'Serra,' into the valley of the River Parahiba, and through the principal coffee-producing districts, will be about two hundred miles in length. The first section of forty miles was commenced in 1855, and will be completed about the middle of 1857. The survey was made across a dense primeval forest, and in many places through water 5 feet, or 6 feet deep. Great difficulty was encountered in executing the earth-works with slave labour and inadequate tools; by degrees, however, European methods were introduced by Mr. E. Price, our Associate, the Contractor, and under the superintendence of Mr. C. B. Lane (M. Inst. C.E.), the Engineer-in-chief to the Home Department of the Brazilian Government, the railway promises to become a fine enterprise.

Our Associate, Mr. Charles Neate, is also engaged under the Brazilian Government, in constructing important hydraulic works at Rio de Janeiro. They consist of quay walls along the sea-front of the city, with piers and jetties, all formed of granite masonry set in lias mortar, for which the limestone is sent from England. The ravages of the sea-worms are so considerable, that all the timber used is required to be thoroughly creosoted.

In Canada, the railway undertaken by Messrs. Peto, Brassey, Betts, and Jackson, may be said to be complete, with the exception of the link to be formed by the Victoria tubular bridge across the St. Lawrence, which is now in progress.

On the Continent, gradual extensions of all the main lines are

being made. The Lombardo-Venetian system has been transferred to a powerful Company, now preparing to act with great energy in the prosecution of their plans.

The Victor Emmanuel line, under the direction of Mr. Bartlett, (M. Inst. C. E.,) acting for Mr. Brassey, (Assoc. Inst. C. E.,) the Contractor, is approaching the chain of the Alps, for the traversing of which preparations are being made, and experiments upon the machinery for the works of tunnelling on a large scale, are being tried. That portion of the line from Aix les Bains, passing through Chambery to St. Jean de Maurienne, upwards of fifty-five miles in extent, was opened for public traffic last October. The works were originally laid out, and to a great extent executed, under the direction of Mr. Nieumann, but he was succeeded last year by Mr. Rineo, under whose supervision they are now carried on.

In Turkey, and in Russia, extensive projects both for railways and steam navigation are being agitated. In Egypt, the energetic viceroy Said Pacha, is completing the railway communication between Cairo and Suez, spanning the Nile by a vast iron bridge at Kaffre Azzayat, and has confided to Mougel Bey the construction of the preliminary works for the canal across the Isthmus of Suez, advocated by M. Ferdinand de Lesseps; whilst he has authorised the establishment upon the Nile and the Mahmoudieh Canal, of a complete system of steam towing-vessels and barges, now in course of construction in this country.

In most of these works our Members are actively engaged, and it may be hoped that accounts of them will be brought before the Institution, as they are completed.

One of the most important, as well as most interesting projects of the period is the Submarine Electric Telegraph Cable proposed to be laid from Valentia, on the west coast of Ireland, to St. John's, Newfoundland, a distance of sixteen hundred miles along the bank, or plateau, discovered by Lieutenant Maury, over which the greatest depth of the ocean does not exceed 2,070 fathoms. By the new method of enclosing the insulated conducting wires, within a covering of ropes composed of small wires, laid in the opposite direction to that of their general 'lay' in the cable, a light and flexible cable is formed, which is stated to be capable of bearing the strain of depositing in those depths, and having no tendency to 'kink,' or twist, during the process. This ingenious modification of the usual construction of cable was devised by Mr. Brunel, V.P., whose co-operation was sought by Mr. Cyrus Field and Mr. J. W. Brett, the projectors, under the advice of Professor Morse. The result of this daring project for connecting the old with the new world, will (if successful,) be more effectual than any efforts of diplomacy, in cementing that intimate union, so desirable for the true interests of the two countries.

The metropolitan questions of the sewerage, the new streets, and the bridges, remain as undecided as at the period of the last Report.

The principal Papers read during the past session, were:—"On the Construction of Stationary Floating Bodies," by G. Herbert; "On the Application of Volute Springs to the Safety-valves of Locomotive Boilers," by J. Baillie; "Description of an Improved Form of Safety-Valve," by J. Fenton (M. Inst. C. E.); "On the Vertical Structure of the Primary Rocks, and the general character of their gold-bearing varieties," by Evan Hopkins; "On the Relative Proportions of the Top, Bottom, and Middle Webs of Iron Girders and Tubes," by J. M. Heppel, (M. Inst. C. E.); "On the Past and Present Condition of the River Thames," by H. Robinson, (Assoc. Inst. C. E.); "On Mental Calculation," by G. P. Bidder, (V.P., Inst. C. E.); "On the Causes of the Explosions of Steam Boilers," by W. K. Hall; "On Improvements in Diving Dresses, and other Apparatus for working under Water," by J. W. Heinke, (Assoc. Inst. C. E.); "On Steep Gradients of Railways, and the Locomotives and Stationary Engines employed," by C. R. Drysdale (Assoc. Inst. C. E.); "On the Junction of the Atlantic and Pacific Oceans, and the Practicability of a Ship Canal, without Locks, by the valley of the Atrato," by F. M. Kelley; and "On the Progressive Construction of the Sunderland Docks," by J. Murray, (M. Inst. C. E.).

It must be apparent how much still remains to be communicated to the meetings, even by merely selecting from among the ordinary subjects of professional engagement.

The following Telford Medals, and Council Premiums of Books have been awarded to the Authors of some of the communications:—

A Telford Medal, and a Council Premium of Books, suitably bound and inscribed, to John Murray, M. Inst. C. E., for his paper "On the Progressive Construction of the Sunderland Docks."

A Telford Medal, to John Mortimer Heppel, M. Inst. C. E., for his paper "On the relative proportions of the Top, Bottom, and Middle Webs of Iron Girders and Tubes."

A Telford Medal, to Henry Robinson, Assoc. Inst. C. E., for his paper "On the Past and Present Condition of the River Thames."

A Telford Medal, to Charles Robert Drysdale, Assoc. Inst. C. E., for his paper "On Steep Gradients of Railways, and the Locomotives and Stationary Engines employed."

A Telford Medal, to Frederick M. Kelley (New York, U.S., America) for his paper "On the Junction of the Atlantic and

Pacific Oceans, and the practicability of a Ship Canal, without Locks, by the Valley of the Atrato."

A Council Premium of Books suitably bound and inscribed, to George Herbert, for his paper "On the Construction of Buoys, Beacons, and other Stationary Floating Bodies."

A Council Premium of Books, suitably bound and inscribed, to Evan Hopkins, for his paper "On the Vertical Structure of the Primary Rocks, and the general character of their Gold-bearing Varieties."

A Council Premium of Books, suitably bound and inscribed, to John William Heinke, for his paper "On Improvements in Diving Dresses, and other Apparatus for working under Water."

A Council Premium of Books, suitably bound and inscribed, to John Baillie (Pesth, Hungary,) for his paper "On the Application of Volute Springs to the Safety-valves of Locomotive and other Boilers."

A Council Premium of Books, suitably bound and inscribed, to William Kemble Hall (U. S. America), for his paper "On the Causes of the Explosions of Steam Boilers."

Almost all these papers induced animated and useful discussions, frequently occupying two, or more evenings.

The Council would have desired to mark the sense they entertain, in common with the general body, of the great value of Mr. Bidder's communications on Mental Calculation. It is, however, a rule not to award any medals to Members of Council. They are therefore restricted to recording the obligation of the Society for those interesting and unique lectures, and to proposing a special vote of thanks to him.

Mr. G. Herbert's paper described a form of buoys and beacons, and a system of mooring them from their centres of gravity, of which most favourable reports had been made; they had been moored in very exposed situations, where they had proved their superiority, by being always visible, and deviating but slightly from the perpendicular, at times when buoys of the old form were almost entirely submerged, and were only visible at intervals, in a horizontal position, in the trough of the sea.

Mr. Baillie communicated an account of the volute springs, stated to be successfully applied by him, not only to locomotive engines and railway-carriages, as draw and buffer springs, but also as bearing-springs for common waggons, and for several mechanical uses, and latterly to the safety-valves of large area, adopted generally for the boilers of the locomotives of the Hungarian and Austrian railways, in the direction of which Mr. Baillie is engaged.

Incidental to this subject, Mr. Fenton, (M. Inst. C. E.) intro-

duced his improved safety-valve, of a spherical form, resting upon a hemispherical seat, with a hemispherical cup bearing upon the valve. This construction, especially when used in the form of the double valve, was said to insure the adequate discharge of the steam, and to preclude the possibility of the hanging up of the valve, from which such serious effects frequently arise.

On the same evening, a description was given of the 'Wien Raab,' locomotive engine, constructed by Mr. John Haswell, the locomotive superintendent of the Vienna and Raab Railway. This engine with its eight wheels, all coupled, was, from its weight and size, an object of great curiosity at the Exhibition at Paris, in 1855. On the Sömmering Incline of 1 in 40, it has drawn loads of 110 tons, at a speed of nearly twelve miles per hour, passing round curves of about 600 feet radius. Volute springs were used on this engine and boiler for all purposes.

Analogous to these communications was the paper by Mr. C. R. Drysdale, "On Steep Gradients of Railways, and the Locomotives and Stationary Engines employed." It compared the results of some of the performances of locomotives, of various construction, with those of stationary engines working ropes, and also with the atmospheric system; examining the systems with the view of determining the most economical and best manner of effecting the passage of mountain chains by railways.

Mr. Evan Hopkins' paper on Gold-bearing Rocks, whilst proposing a theory of the structure of the primary rocks not in accordance with received opinions, gave the results of personal investigation of extensive mineral districts in various parts of the world, and induced a very animated and useful discussion.

Mr. Heppel's paper had for object the investigation of the forces to be resisted by the middle webs of Iron Girders; taking the cases of plates subjected to the action of various direct forces, some compressile and others tensile, simultaneously applied in different directions;—of rectangular plates, held in equilibrium by lateral forces, applied in couples along their sides;—of the middle webs of girders under given loads, with rules for the computation of the thickness;—of the distribution of loads with rules for the thickness of the parts;—of the effect of horizontal strains on the middle web;—and of the increase to be made in the thickness of the middle web, beyond that already arrived at, in order to deal with the horizontal and diagonal strains to which it was exposed. This interesting investigation appropriately followed Mr. Barton's paper of the last Session, but did not yet exhaust the subject.

Mr. Robinson's paper on the "Past and Present Condition of the River Thames," whilst proposing an engineering work for which neither the profession nor the public were prepared, gave

an excellent historical account of the river, and drew from a City legal functionary, in the course of the discussion, one of the most interesting speeches ever addressed to the meetings.

Mr. Bidder, on account of the novelty of the subject, was permitted to deviate from the ordinary course of proceedings and to address the Members orally, on the subject of Mental Calculation, with the object of demonstrating, that the system could be taught to children, and be acquired with greater facility and less irksomeness, than ordinary arithmetic. The phenomena connected with the powers of memory were examined, and it was shown that, by proper training, the infant mind could be made almost insensibly to accumulate, gradually, a store of facts, to be brought forward and utilized without effort when required. The process of teaching must, however, be by convincing the reasoning faculties, and not by merely impressing upon the memory certain symbols, and attaching to them accepted values. This system, as practised in his own case, was explained by Mr. Bidder, and exemplified by calculations according to his own system and by the ordinary methods. In speaking of these lectures,

Mr. R. Stephenson,—President,—said, "I need scarcely ask you, whether a vote of thanks shall be offered to Mr. Bidder, for the very interesting exposition he has given of the system of Mental Calculation, which he may be said to have invented, and which he uses with such remarkable facility. You must all have been as much struck with the simplicity of the processes, as with the clearness of the modes of reasoning by which those processes were arrived at, and the rapidity of the application of the system, but you are not aware of the labour it has cost our friend to prepare these lectures, and nothing but his friendship for me, and anxiety to signalize my Presidency, by what must be an unique production, would have induced him to undertake the task. His proposition for teaching to youth a system of mental arithmetic is well-deserving of serious consideration; but whatever training may be essayed, I fear that few Bidders will result; it will be rare to find the large capacity and pure analytical mind which characterizes our friend, and without which the process we have heard explained would be but of little use."[1]

Mr. W. K. Hall's paper "On the Causes of the Explosions of Steam Boilers," and Mr. Heinke's paper on "Diving Apparatus," were good communications inducing useful and prolonged discussions.

Mr. F. M. Kelley's paper "On the Junction of the Atlantic and Pacific Oceans, by a Ship Canal, through the valley of the

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[1] *Vide* Min. of Proc. Inst. C.E., vol. xv., p. 280.

Atrato," brought forward a most important subject, well deserving the consideration of the English, French and American Governments, which Mr. Kelley claimed for it, and in pursuance of which he had expended much time and money, as all the surveys he brought forward had been made at his individual cost.

It must be gratifying to the Institution, to receive such papers as these from their professional brethren from the other side of the Atlantic.

Mr. J. Murray's description of the "Progressive Construction of the Sunderland Docks," was precisely the kind of paper most desirable for the Meetings. It deserves the careful study of all the junior members of the profession; is replete with useful information, giving practical details of a large work which has been more than usually successful, and as an example of Dock Engineering stands almost unrivalled in this country. The system of sluicing, or scouring of the entrance, particularly deserves attention, as the volumes of water simultaneously emitted from numerous apertures, by means of Armstrong's hydraulic apparatus, possess an almost irresistible force, sufficing for the complete removal of the accumulation of silt, sand, and débris brought by storms, or deposit, within the entrance channel, and showing that this mode of application of water-power might be adopted in other positions with great advantage.

It is much to be regretted, that the donations to the Library have been fewer than usual, yet it is hoped that, as a matter of convenience to the Members themselves, they will, in future, be more mindful of the necessity of contributing copies of all new professional and technical works; otherwise the library cannot continue to maintain its utility for consultation and reference.

The valuable charts published under the directions of the Lords Commissioners of the Admiralty, continue to be presented through our Associate, Captain Washington, R. N., the Hydrographer. We also receive the Transactions and Proceedings of the different English and Continental Scientific Societies, in exchange for those published by the Institution.

The following sums have been liberally presented during the past session for the purchase of books:—

A. H. Bampton . .	£10	10	0
W. R. Le Fanu . .	5	0	0
Henry Maudslay . .	10	0	0

The Members will learn with regret, the decease of Mr. C. Brewin, of Birmingham, who contributed, at various times, a large number of rare and valuable tracts, principally relating to Inland Navigation and Canals.

Her Majesty's Commissioners of Patents have promised, through

Mr. Bennet Woodcroft, a complete set of all their publications, including the Specifications of Patents and Indexes, numbering between 300 and 400 volumes, which will be specially arranged for easy consultation. The Honourable the East India Company have likewise liberally announced their intention of presenting a collection of valuable Reports and other documents, having reference to the Public Works of India, and of continuing to transmit to the Institution copies of similar Reports as they appear. For this donation the Institution is mainly indebted to Mr. Juland Danvers.

The amount of arrears of subscriptions for 1856, due November 30th, is,—

	£.	s.	d.	£.	s.	d.
From Members of all classes, residing abroad .	106	12	0			
From Members of all classes, residing in England	339	10	6			
				446	2	6
Total amount of arrears of the previous years, exclusive of 1856, is,—						
From Members of all classes, residing abroad .	386	10	0			
From Members of all classes, residing in England	307	12	0			
				694	2	0
Total . .				£1,140	4	6

This amount of arrears is larger than ought to exist, and it will be recommended to the next Council to examine the list, with a view to obtaining payment of the sums due, or taking other steps for reducing the amount.

The tabular statement of the transfers, elections, deceases, and resignations of Members of all classes, during the years 1854-55, and 1855-56, appears thus:—

— .	Honorary Members.	Members.	Associates.	Graduates.	Annual Increase.
1854-55.					
Transferred to Members . . .	..	..	4	..	
Elections	..	7	24	..	31−16=15
Deceases	1	..	5	1	=16
Resignations	..	2	6	1	
1855-56.					
Transferred to Members . . .	..	..	4	..	
Elections	..	10	24	..	34−25=9
Deceases	1	11	6	..	=25
Resignations	..	1	6	..	
Members of all Classes on the Books, Nov. 30, 1856	26	289	466	16	797

If the Honorary Members and Graduates are omitted from the calculation, the annual increase of Members and Associates stands thus:—

Years.	Members elected.	Associates elected.	Total elected.	Deceases, Resignations, and Erasures.	Effective Increase.
1851	3	52	55	21	34
1852	8	42	50	13	37
1853	10	33	43	38	5
1854	20	37	57	33	24
1855	7	24	31	13	18
1856	10	24	34	24	10

The following Member and Associates having tendered their resignations, have been permitted to retire from the Institution:—

Mr. Edward Bury, Member; and Messrs. Henry Banister, Joseph Aaron Joseph, J. D. Morries Stirling, Captain Fitz Roy, R.N., Captain C. J. B. Riddell, R.A., and the Reverend Stephen John Rigaud, D.D., Associates.

The deceases during the past year have been:—The Reverend Dr. Buckland, Dean of Westminster,—Honorary Member;—Messrs. Michael Andrews Borthwick, James Bremner, John Chisholm, Samuel Clegg, jun., George Haden, Charles Rammell, John Urpeth Rastrick, James Meadows Rendel, Thomas Henry Statham, Francis Whishaw, and Thomas Jackson Woodhouse, —Members;—Lieut.-General Duncan McLeod, Messrs. James Beatty, Thomas Cubitt, David McIntosh, John Fletcher Miller, and Robert Wilkins,—Associates.

The memoirs of our late friends will be found in the Appendix to this Report (page 102).

The statement of the Receipts and Expenditure exhibits a satisfactory financial position, enabling the current expenses to be met, and leaving a balance to be devoted to bringing up arrears of publication, or for any incidental expenses.

Since Christmas 1855, there have been printed and issued of the Minutes of Proceedings:—Parts 2 of Volumes 11, 12, and 14, for the Sessions 1851-2, 1852-3, and 1854-5, with the entire Volume 15 for Session 1855-6. There remain to be completed, Parts 2 of Volumes 7, 8, and 10, for the Sessions 1848, 1849, and 1850-1, with the entire Volume 13 for Session 1853-4. The Papers of Volume 13 are in type, and the editing of all is proceeding fast.

The Papers, as soon as they are read, will in future be prepared

for publication, and be issued as rapidly as may be found practicable.

At the close of his excellent address on taking the Chair, on his election as President, Mr. Robert Stephenson said, in reference to the duration of the tenure of the office of President, that he would not then express any individual opinion, as he considered that his mission was to represent the views of the collective body, and to conform to any course which might be deemed for the general good; these expressions he reiterated at the first meeting of the present Session, adding, that his services were at the command of the Institution, if it was considered desirable that he should hold the post for anotheryear. The name of Mr. Robert Stephenson, M.P., is therefore proposed as President. Mr. John Penn, whose precarious health has prevented his giving that constant attendance he so much desired and would otherwise have done, has requested permission to withdraw from the Council. The new names added to the balloting list, submitted for your consideration, are Messrs. Joseph Cubitt, Thomas Elliot Harrison, and John Murray, as Members; and Sir Macdonald Stephenson, and Messrs. Robert W. Kennard, Sancton Wood, and M. Digby Wyatt, as Associates.

It will be recollected, that at the last Annual Meeting, Mr. Charles Manby, who has held the post of Secretary for upwards of seventeen years, tendered his resignation. He has, however, held the position until the present time, and has expressed his readiness to continue to act as Secretary, gratuitously, as long as his services are considered useful to the Institution. But in the month of June 1856, Mr. James Forrest, who has been for the last fourteen years more or less intimately connected with the Institution, in which he was to some extent brought up, entered on the post of Assistant Secretary, with the salary formerly devoted to Mr. Manby.

Before retiring from the charge confided to them, the Council would again impress upon the Members the vital importance of communicating good Papers to the Meetings, and of giving their personal attendance, in order to keep up the interest of the discussions, by which alone the utility of the Institution, and its position among the Scientific Societies of the Metropolis can be maintained.

ABSTRACT *of* RECEIPTS *and* EXPENDITURE

RECEIPTS.

Dr.	£.	*s.*	*d.*	£.	*s.*	*d.*
To Balance in the hands of the Treasurer				715	3	5
— Subscriptions and Fees:—						
Arrears	140	14	0			
Current	1,505	14	0			
Fees	110	5	0			
				1,756	13	0
— Publication Fund				72	19	0
— Council Premiums				44	12	0
— Publications:—Sale of Minutes of Proceedings				7	9	10
— Telford Fund:—						
Dividends—6 months, due Christmas, 1855, on £2,551 15*s.* 10*d.* 3 per Cent. Reduced Consols	35	14	6			
6 months, due Lady-day, 1856, on £2,342 17*s.* 1*d.* 3 per Cent. Reduced Consols	32	16	0			
6 months, due Midsummer, 1856, on £2,551 15*s.* 10*d.* 3 per Cent. Reduced Consols	35	14	6			
6 months, due Michaelmas, 1856, on £2,342 17*s.* 1*d.* 3 per Cent. Reduced Consols	32	16	0			
				137	1	0
				£2,733	18	3

from the 1ST DEC., 1855, *to the* 30TH NOV., 1856.

PAYMENTS.

Cr.	£.	s.	d.	£.	s.	d.
By House, Great George Street:—						
Rent	353	2	6			
Rates and Taxes	7	10	0			
Insurance	18	19	9			
				379	12	3
— Salaries:—						
Secretary from Michaelmas 1855 to Midsummer 1856	225	0	0			
Assistant Secretary from Midsummer to Michaelmas 1856	75	0	0			
				300	0	0
— Commission on Collection of Subscriptions				81	17	4
— Clerk, Messenger, and Housekeeper				221	17	0
— Postage and Parcels:—						
General	46	16	3			
Parcels	0	5	8			
				47	1	11
— Stationery, Engraving, and Printing Circulars, Cards, &c.				95	19	11
— Coals, Candles, Oil, and Gas:—						
Coals	36	0	0			
Candles	4	12	6			
Oil	9	7	0			
Gas	38	3	6			
				88	3	0
— Tea and Coffee				32	2	10
— Library:—						
Books	26	13	4			
Periodicals	26	18	10			
				53	12	2
— Publication:—Minutes of Proceedings				565	14	9
— Telford Premiums				40	8	1
— Council Premiums				31	17	0
— Diplomas for Members				6	7	2
— Manuscripts, Original Papers, and Drawings				4	11	9
— Legal Expenses, Tooke & Co., Disbursements out of Pocket				8	9	2
— Incidental Expenses:—						
Gratuities and Christmas Gifts	1	17	0			
Occasional Assistance	0	15	0			
Assistance at Meetings	8	7	0			
Beating Carpets and Sweeping Chimneys	3	1	0			
Household Utensils, Repairs, and Expenses	46	9	10			
				60	9	10
				2,018	4	2
— Balance in the hands of the Treasurer				715	14	1
				£2,733	18	3

Examined and compared the above Account with the vouchers in the Cash Book, and find them to be correct, leaving a balance in the hands of the Treasurer of Seven Hundred and Fifteen Pounds Fourteen Shillings and One Penny.—November 30th, 1856.

(Signed) RICHARD B. GRANTHAM, J. G. APPOLD, } *Auditors.*
CHARLES MANBY, *Secretary.*

December 15, 1856.

APPENDIX

TO THE

ANNUAL REPORT.

MEMOIRS.

THE REV. WILLIAM BUCKLAND, D.D., F.R.S., F.G.S., &c., Dean of Westminster, and Reader in Mineralogy and Geology in the University of Oxford, was born at Axminster, in the county of Devon, in the year 1784. He received his early education at Tiverton School, whence he was removed to St. Mary's College, Winchester, and thence to Oxford in 1801, where he was elected to a scholarship on the Exeter Foundation of Corpus Christi College. He took his degree of B.A. in 1805, just before the institution of the system of classical honours. In the second, or third year of his residence at Oxford, he took his first lessons in Geology from Mr. Broderip (the late Magistrate of the Westminster Police Court), then of Oriel College, and first studied the oolite formation and the green sand in the Vale of Pewsey. In the interval between obtaining the degrees of Bachelor and Master of Arts, he attended the lectures of Dr. Kidd, on Mineralogy and Chemistry, and of Sir C. Pegge, on Anatomy. Of these lectures he made copious notes. During the vacations of his early years at Oxford, he paid frequent visits to Lyme Regis, where he first met Sir H. De la Bêche, who was collecting fossils at that place. In the summer of 1808, he made his first geological tour, alone, on horseback, from Oxford across the chalk downs of Berks, Wilts, and Dorset, to Corfe Castle, in the Isle of Purbeck. In 1809, he explored, also alone, a large part of South Devon, examining minutely the formations, and collecting specimens of the geology of the district. In 1810, he made a tour in the centre and north of England, exploring the, then unknown, extent of the various strata, and colouring the results on Carey's large Map of England. In the spring of 1811, he visited Kent and Sussex, along with the

Rev. W. Conybeare. Later in the same year, he again crossed England, by another route, into Scotland, returning from Inverness to Port Patrick, and from Dublin to North Wales. In the years 1812-15, he made extensive tours, with Mr. Greenough, collecting materials for the Geological Map of England. Thus, in early years, he showed a decided predilection for the study of geology; and it was during these journeys, that he laid the foundation of that extensive collection of the remains of the larger fossil mammalia, and other animals, from caves and subterranean localities in England and on the Continent, and of specimens of minerals, which he has bequeathed to the University of Oxford, and are now preserved in the Clarendon Museum. For forty years, Dean Buckland spared neither expense, time, nor trouble, in procuring and arranging specimens to render this collection complete, and worthy of the University. His travels were undertaken with this object, and his great desire was to make the collection the means of advancing the science which it was intended to illustrate. In 1815, he presented to the Geological Society, in conjunction with his old friend Dr. Conybeare, the present Dean of Llandaff, his first important paper, "On the Coasts of the North of Ireland,"[1] the result of a personal inspection, in 1813, of about fifty miles of coast. From 1812 to 1824, he rode on horseback, once, or twice, in each year, from Oxford to Axminster, in Devon, frequently visiting, on his way, the Rev. J. Townsend, of Pewsey, and the Rev. B. Richardson of Farleigh Castle, the first fellow-labourer of Dr. W. Smith.

Having acquired reputation for scientific attainments in geology, in 1814, he was appointed Reader in Mineralogy, on the resignation of Dr. Kidd, the successor of Sir C. Pegge. In 1815, he published the first comparative table of the strata of England and of those of the Continent, as arranged by Werner. In 1816, he visited Germany, accompanied by Mr. Greenough and the Rev. W. Conybeare, and proceeded with the former through Silesia, to Poland, Austria, and the North of Italy. He took this opportunity of enlarging his comparative tables, and of visiting Werner and other of the principal German geologists. In 1820, he again travelled in Germany and Bohemia, with Mr. Greenough and Count Breüner, of Vienna, and returned by way of Switzerland. In 1818, he obtained an endowment from the Crown, for a new office of Reader in Geology, and from that time down to the year 1849, when he was taken ill, he gave annually one course of lectures on Mineralogy, and one course on Geology. This appointment he continued to hold, after being made Dean of Westminster; and whether his class was small, or large, he invariably took great pains in preparing the lectures, generally writing fresh notes for

[1] *Vide* Trans. Geol. Soc., vol. iii.

every course, and sparing no expense in obtaining new, or interesting specimens to illustrate any particular subject. His geological lectures were characterised by such clearness and comprehensiveness, accompanied by aptness of illustration, that they were attended with marked success. When he first commenced his lectures, Geology, as a science, was, almost, in its infancy; and much of its vigorous advancement in subsequent years is due to the interest excited among thinking minds, by Dr. Buckland's Oxford lectures.

In the same year, 1818, Dr. Buckland was elected a Fellow of the Royal Society. In 1820, he delivered, before the University of Oxford, a lecture, which was afterwards published, under the title of "Vindiciæ Geologicæ; or, the Connexion of Geology with Religion Explained." The object of this lecture was to show, that the study of geology, so far from being irreligious, or atheistic in its consequences, had a tendency to confirm the evidences of natural religion, and that the facts developed by it were consistent with the accounts of the Creation and the Deluge, as recorded in the Book of Genesis. In 1822, Dr. Buckland communicated to the Royal Society an "Account of an assemblage of fossil teeth and bones of elephants, rhinoceroses, hippopotami, bears, tigers, hyænas, and sixteen other kinds of animals, discovered in a cave at Kirkdale, Yorkshire."[1] For this publication the Society awarded him their highest honour—the Copley Medal. This Paper was made the foundation of a treatise, published in 1823, entitled "Reliquiæ Diluvianæ; or, Observations on Organic Remains attesting the Action of a Universal Deluge," a work which proved of essential service, not only in the promotion of geological science, but in reconciling its study to many persons who viewed it with suspicion, as adverse to religion. In 1824, he was elected President of the Geological Society, of which he was one of the earliest members, having joined it in 1813.

In the following year, Dr. Buckland vacated his fellowship, by accepting, from his College, the living of Stoke Charity, near Whitchurch, Hants; and soon after he was promoted to a canonry in the cathedral of Christ Church, and married Mary, the eldest daughter of Mr. Benjamin Morland, of Sheepstead-house, Abingdon. In 1826 and 1827, he again explored parts of France, Germany, Austria, and Switzerland, and he was the first English geologist, who examined, with attention, the Val del Bove, on the eastern side of Mount Etna. In the southern portion of the Ardennes, three formations were recognised by Messrs. Buckland and Greenough, occupying the same geological position as in England and Wales, between the carboniferous deposits and the older slaty rocks. He

[1] *Vide* Phil. Trans. for 1822.

also recognised the, comparatively, late geological date of the great upward movement of the Alps,[1] and declared that some of the highly-inclined rocks were contemporaneous with the lias and oolite of this country. The bone caverns of Lunel and the Grotte d'Ozelles,[2] furnished many specimens for the Museum. From 1825 to 1830, he laid before the Geological Society, many Papers relating to continental geology, as well as researches among the fossils of Portland, Lyme Regis, and the Mendips, the Isle of Wight, the Isle of Purbeck, and the coast of Weymouth, and on coprolites and fossil sepiæ; all evidencing his skill as a geologist and palæontologist. In 1832, he presided over the second meeting of the British Association, which was held in Oxford. On this occasion, he gave a lecture on the Geology of the neighbourhood of Oxford, when he enforced the importance of the application of a knowledge of geology to agricultural improvement; pointed out many defects in the ordinary system of drainage, which could be remedied by a knowledge of the structure of the strata; and adverted to the possibility of reclaiming the peat bogs of Ireland. He also gave a lecture "On the Fossil Remains of the Megatherium," recently imported into England from South America; and commented on a scale of geological colours, which had been adopted by the Board of Ordnance. About this time, he was selected by the special Trustees, under the will of the late Earl of Bridgewater, to write one of a series of eight treatises, "On the Power, Wisdom, and Goodness of God, as manifested in the Creation." The branch assigned to him was "Geology and Mineralogy, considered with reference to Natural Theology." The discovery of new facts by the inductive process pursued by geologists had materially advanced the progress of geological science in the few preceding years, and, modifying in this work the previous diluvial theory, Dr. Buckland brought the weight of his authority to support the views now generally received upon the subject. In the same year he, conjointly with the Rev. Dr. Conybeare, communicated to the Geological Society a valuable memoir, "Description of the South-Western Coal District of England,"[3] which has stood the test of more than thirty years, and, being published separately, is still consulted by scientific men, as a standard work.

Subsequently to this he read many papers before the Geological Society, most of which appeared from time to time in the "Transactions." He also contributed to several scientific journals, articles on various special subjects; and the Agassiz Catalogue contains a list of sixty-six memoirs and essays by Dr. Buckland, spread over

[1] *Vide* Annals of Philosophy. New Series, I., iv., 450.
[2] *Vide* Trans. Geol. Soc., vol. i.
[3] *Vide* Trans. Geol. Soc., 2nd Series, vol. i.

the whole period of his life in Oxford, from the year 1813, giving the results of many years of study of the geological and mineral structure of the earth.

In 1845, Dr. Buckland was preferred by the late Sir Robert Peel to the Deanery of Westminster, vacated by the promotion of Dr. Samuel Wilberforce to the Bishopric of Oxford. In his new capacity Dean Buckland was worthy of all praise, for having set an example to other cathedral bodies, in facilitating the admission of the public, to view the monuments and other objects of historic interest contained in the Abbey Church—for the numerous and judicious alterations he suggested and caused to be effected in the Abbey and its precincts;—the better administration of the funds, and the complete remodelling of the buildings and the government of St. Peter's College, Westminster. He was a most zealous sanitary Reformer, in which capacity he had to encounter the usual opposition from the advocates of "letting matters alone." But opposition only excited his ardour and insured the ultimate success which he enjoyed in proportion to the difficulties he had encountered. He was, however, sensibly affected when the breaking out of a fever in the precincts of Westminster was ascribed to his sanitary reforms,—a most unfounded charge, which recoiled on those who had promulgated it, for the purpose of arresting the useful career of this energetic and good man.

He exerted himself actively in the improvement of the supply of pure water to the Metropolis, and examined the questions of obtaining it from the Thames and other rivers, and from wells sunk into the chalk.

Dr. Buckland became a Fellow of the Royal Society, in 1818, and was a member of the Council from 1827 to 1849. He was also, as has been previously stated, a Fellow of the Geological Society, and likewise of the Linnean, Zoological and Geographical Societies. In 1842, he was elected an Honorary Member of the Institution of Civil Engineers;—and there is scarcely a Natural History, or Philosophical Society of any importance, either in Europe, or the United States, which did not similarly strive to do him honour.

In 1847, he was appointed a Trustee of the British Museum, and for two years took the greatest interest, in arranging and increasing the geological collection there. At the first foundation of the Museum of Practical Geology, he laboured diligently, in conjunction with his old friend the late Sir Henry De la Bêche.

He was much attached to agricultural pursuits, watching, with great interest, the development of the introduction of new manures, the application of chemical science, and the adaptation of mechanical contrivances to farming. He was a regular visitor at the annual meetings of the Royal Agricultural Society, and took

every opportunity of enforcing his views among the farmers, with whom he was a great favourite.

From the period of his adopting Oxford as his residence, he took an active interest in promoting all measures for improving and beautifying the City. In 1818, with the aid of the late Dr. Kidd, Dr. Bliss, Mr. Hickman, Alderman Sadler, and other influential men, he succeeded in establishing the works for lighting the University and City with gas, at that time a novelty. His friend the late Mr. A. Manby, undertook the construction of the apparatus at the Horsely Ironworks, and it was in a great degree owing to the support and scientific counsel of Dr. Buckland, who was the Chairman of the Company, a post which he retained for a long period of years, that this early attempt was so eminently successful, and that the Company has continued to flourish to the present time.

He advised numerous local improvements in the buildings of the University and in the streets of the City, and up to within a comparatively recent period took an active interest in promoting all ameliorations of the sewerage and water supply of the City.

Any attempt to notice all the publications of Dean Buckland, or the numerous investigations he engaged in, would extend this sketch far beyond the usual limits; his special studies have been well noticed in the Report of the Royal Society in December, 1856, and it is hoped that a memoir worthy of such a subject may be given to the world by one of his eminent fellow-labourers in the field of geological research. It is from one of the phalanx of talent that was wont to assemble at the meetings of the Geological Society, that the memoir of Buckland should proceed, so as to bring forward vividly all the useful public labours, the well-directed scientific researches, and the anecdotes of the social life of this amiable and worthy man. It has been well said that he was "strong in mind and strong in body; working hard and setting others to work; gathering and giving knowledge; a patient student, a powerful teacher, a friendly associate; a valiant soldier for geology, in the days when she was weak, and an honoured leader in the hour of triumph." The correctness of this description must be evident to all who remember those evenings when Kidd, Conybeare, Smith, Sedgwick, Lyell, Murchison, Phillips, Owen, Daubeny, De la Bêche, Forbes, and others met to do battle for and against some proposition; it was then the well-known steady, firm and determined step of Buckland was looked for, and from the never-absent blue bag, specimens after specimens were drawn to enforce his arguments. Many of those lips are now hushed whose fiery eloquence warmed the latent spark in their hearers, and brought forth present fruits of their labours; but the remembrance of those evenings must ever live.

To the Institution of Civil Engineers Dean Buckland was specially devoted; he looked upon the labours of its Members as inseparable from geological research, and he rarely missed the reading of any paper of importance, taking an active part in the discussion, and whenever his personal aid or influence could be useful, it was most cheerfully given.

The same qualities which pervaded his public career governed his private life, and he was never so happy as when he was surrounded by his family and friends, by whom he was equally admired and loved. His kindness was unbounded; and when his useful career was arrested, his absence was felt as that of the intimate friend and companion of all. He suffered for some years from a diseased state of the bones at the base of the skull, which led to the partial impairment of his mental faculties. During his illness he was most carefully watched by his excellent and amiable wife, and by his eldest son, Assistant-Surgeon to the Second Regiment of Life Guards, and on the 15th of August 1856, he was taken from his family and a large circle of friends, by whom his memory will ever be cherished, with the most vivid feelings of affection.

Mr. MICHAEL ANDREWS BORTHWICK was born at Dunbar, in East Lothian, on the 30th of October, 1810. He received the rudiments of his education under Mr. White, of Dunbar, then a man of considerable reputation as a country teacher, and under whom he made rapid progress. He afterwards completed his studies at the Academy of the ancient burgh of Ayr, at that time, and still, one of the most famous provincial seminaries of Scotland. The Rev. Dr. Memes, a well-known scholar, author, and man of science, was Rector, and took a deep interest in his young pupil, whose constant and indefatigable exertions for learning very soon eclipsed all the other scholars, many of them of a much greater age. Dr. Memes recently assured an old and intimate friend, with pride, that he was astonished at the perfection his former pupil had attained in so short a period. He devoted much attention to mathematics, but he was chiefly distinguished in English composition, and in his knowledge of History and Geography. His memory on almost all subjects was most minute and comprehensive.

The following testimonial from Dr. Memes was given to him on quitting the academy:—

"It is with more than ordinary satisfaction that I discharge, not merely an official duty, but a highly pleasing service, in granting this public attestation in favour of the amiable disposition, persevering industry, and superior talents and acquirements of my

young friend Mr. Michael Andrews Borthwick. From the commencement of his studies in this Institution, under my direction, Mr. Borthwick was distinguished in a very eminent degree, in a class, every member of which was at least respectable for ability and application. I could likewise observe no inconsiderable proof in him of merit, united with goodness of heart, and that this superiority was cheerfully acknowledged by his fellow-students, who seemed equally to respect his acquirements and to love the excellence of his character.

"With regard to the nature and extent of Mr. Borthwick's attainments, these will be found rarely equalled, and seldom, if ever, surpassed, by any one of his standing. As a student in the Rector's Classes in this Seminary, his studies were directed chiefly to Mathematical and Physical Science, and to Geography. In the two first-mentioned departments his merits were so conspicuous, that did I not know from the reports from the masters, and from his having obtained the first rewards in every other class, as also from my own observation, that Mr. Borthwick has most diligently and successfully cultivated other studies, especially languages, I should say, that his genius eminently qualified him to excel in the pursuits of Mathematics and Natural Philosophy. In each of these branches, especially the former, he has already made a progress far beyond his years, and has even carried his studies in Geometry and Analysis to a height seldom attempted out of a University. In Geography his diligence and success were sufficiently apparent from his receiving the first prize-medal in the senior division of a numerous class; and I may add to this, that I seldom failed to receive an answer to questions not resolved by any other of his compeers, while several voluntary essays on Physical Geography did great credit to his acuteness and extent of information.

"Expressing my sentiments thus warmly, it is unnecessary to add, that I consider Mr. Borthwick to be a young gentleman deserving of every encouragement; and that he will form an ornament to any profession in which eminent talents, unwearied industry, very considerable and varied attainments, inflexible integrity, and great docility are requisite. I express my conviction also, that he will prove an invaluable assistant to those under whom he may be employed, especially in any scientific capacity.

"If to this public testimonial, my own private feelings can add any weight, I would say that I shall never cease to feel a warm and personal interest in his happiness and success; and that it will ever afford me the most sincere satisfaction to be informed of his prosperity and welfare in life.

(Signed) "J. L. MEMES, LL.D.,
"Rector of Ayr Academy.

"Academy, Ayr, Nov. 14th, 1826."

Mr. Borthwick came to London in the beginning of October 1827, where, after a short interval, he was engaged as an assistant by Mr. Walker (M. Inst. C.E.), then residing at Limehouse, and in his employment he continued for a period of eleven years. During that time he had an opportunity of seeing, and of being engaged in a great variety of important works. Among others may be mentioned: the Lighthouse at the Needles, the renovation of Blackfriars and the alteration of Westminster Bridges, the completion of Plymouth Breakwater, the embankment of the Thames at the Houses of Parliament, the construction of the Hull Docks, and the important works in the Harbours of Glasgow, Belfast, Dover, and Leith.

Whilst acting generally as Mr. Walker's private Secretary, Mr. Borthwick had an opportunity of gaining a knowledge of general business—a most essential element in all professions, not unfrequently neglected; and, enjoying the confidence of Mr. Walker, he had the advantage of constantly meeting numerous official men and others high in rank and importance. From this association he derived great benefit, and he always gratefully acknowledged the kindness which had been thus shown him.

Early in the year 1833, he became an Associate of the Institution, and in 1845 he was transferred to the class of Members. He was indirectly connected with the Institution from a very early period, took a deep interest in its progress, and bestowed great time, research, and labour in editing the first volume of its Transactions, which was got up mainly through his exertions; all the articles in it underwent his anxious revision, while many of them were actually rewritten, and the Introduction was entirely furnished by him. He also contributed a Memoir, which appeared in this volume, "On the use of Cast-Iron in Piling, particularly at the Brunswick Wharf, Blackwall."[1] In this Paper he gave a short sketch of the introduction and use of cast-iron in piling, and described, in detail, the works at the Brunswick Pier, which were executed under the superintendence of Mr. G. P. Bidder, V.P., Messrs. Walker and Burges being the Engineers. For this communication he received a Telford Medal; and his services to the Institution were officially acknowledged by Mr. T. Webster, Secretary, by order of the Council:—

"March 15, 1837.

"I am also directed to convey to you the thanks of the Council, for the zeal with which you have laboured to render the volume of the Transactions so worthy of the body from which it emanates. The Council were not aware of the great exertions which you had made in procuring materials for the Introduction, and of the labour

[1] *Vide* Trans. Inst. C. E., vol. i. pp. 195-205.

which you had bestowed in superintending the volume during its progress through the press, till the President (Mr. Walker) mentioned them on the last evening. Your opportune and valuable assistance most certainly entitles you to the warmest thanks of every member and well-wisher of the Institution; and I trust that some more public acknowledgement will, ere long, be made of the essential services which you have rendered."

During this period Mr. Borthwick employed his leisure hours in contributing largely to several useful publications in London, embracing a variety of subjects, not exclusively professional. He also took much interest in the framing of the Standing Orders of Parliament in relation to engineering practice, of which a great portion were adopted from his suggestions; and, from the parliamentary and legal knowledge which he acquired in Mr. Walker's office, he eventually became a most useful auxiliary in the framing of engineering clauses, and in carrying Bills through Parliament. His varied knowledge, his quick intuitive perception and forethought, and his excellent memory, rendered him extremely useful in cases of this nature.

When railways were becoming the leading engineering feature of the day, Mr. Borthwick naturally turned his attention in that direction; and in the year 1837, Mr. Walker becoming the Engineer-in-chief of the Northern and Eastern Railway, Mr. Borthwick was appointed the Resident Engineer, and afterwards the Manager, of the line. It was opened at first as a single line for a distance of twenty-two miles; and, notwithstanding the numerous stations and the comparatively great passenger traffic, the working was conducted without a single accident. At that time the opening and management of a single passenger line was comparatively a novelty in this country, and the electric telegraph, now so essential in the working of railways, had not then been introduced.

Owing to a change of policy in the direction, Mr. Walker resigned his office as Engineer of the line, and it was confided to the charge of Mr. Robert Stephenson, M.P., President, by whom Mr. Borthwick was continued in his position as Resident Engineer.

Since that time (1839) Mr. Borthwick was constantly engaged along with Mr. Stephenson, in the construction of extensive railway and other works, including the completion of the Northern and Eastern Line to Cambridge, and its extension to Brandon, with branches to Peterborough, St. Ives, and Wisbeach; also to Enfield and Edmonton, Maldon, Witham, and Braintree, Shelford, and Shepreth, with the Newmarket and other Railways. Some idea of the extent of his labours may be formed, from the fact of no less than twenty-two sets of plans and sections of several hundred miles of railway and other works being got up and deposited under his direction, in the memorable year 1845-6. In all these cases he

was constantly engaged, during the progress of the Bills through Parliament; and he took a leading part in the opposition to the London and York and Great Northern Railways (which afterwards merged under the latter title), the proceedings in which continued for two sessions, and occupied the unprecedented period of more than seventy-five days, during which the greatest efforts of labour, skill, and judgment were constantly in requisition.

Mr. Borthwick was afterwards engaged along with Mr. Stephenson in carrying out the Egyptian Railway between Alexandria and Cairo, the first of those undertakings which are likely to be of so much benefit, in facilitating the intercourse between Europe and our Eastern possessions. In the progress of the work he made many visits to Egypt, some of them with Mr. Stephenson, during which he conducted, and assisted in conducting, complicated negotiations with great tact and ability. In these visits he acquired the respect of the authorities, and the friendship of many gentlemen of rank and distinction, whom he accidentally met on his journeys in the East.

For some years Mr. Borthwick was associated with Mr. Stephenson, the late Mr. Tycho Wing, and Mr. Robert Mein, in improvements connected with the drainage works of the Fens, and his management of those complicated and difficult matters, which had been previously in the hands of various Engineers of high standing, gained him the approbation and confidence of the Duke of Bedford and other noblemen and gentlemen interested. He was also associated with Sir John Rennie and Mr. Stephenson in carrying out the Norfolk Estuary Scheme, combining drainage and navigation with the reclamation of land from the sea, a work of great importance; and he was, to some extent, connected with the Netherlands' Land Inclosure Works, which he inspected along with his friend Mr. Bidder, V.P., with whom he was concerned in several other considerable works.

In 1853, Mr. Borthwick went out as Engineer-in-Chief to the Brazils, to report upon and fix the course of a proposed line of Railway from Pernambuco to Paulo Affonso, on the river San Francisco, on which he wrote a very able Report; and it was on his again visiting Brazil, in connection with this undertaking, that he was carried off in the prime of life, in the midst of his professional career.

He left London on the 9th May, 1856, and shortly afterwards, during the passage, was seized with illness of a typhoid character, which continued until his arrival at Pernambuco on the 27th of the same month. His death occurred on the 3rd June following, in the house of his friend, Mr. J. Scott Tucker, the Resident Engineer of the Railway by whom, as by his faithful and long-attached servant, everything was done, that devotion could prompt, to soothe his last moments.

Throughout his career Mr. Borthwick exhibited mental attainments of no ordinary kind, combined with great energy, indefatigable industry, and judicious application of these powers. He had acquired great theoretical and practical knowledge. His numerous avocations constantly brought him into contact with men of high position in the several professions, as well as with distinguished persons of all classes, from whom he did not fail to acquire useful knowledge and experience; and, from his great resources and the ready use of his powers, his society and advice were much courted. In any disputed question, whether professional, or otherwise, he was always prepared, and as to past and current events, men and things, dates and epochs, and on subjects of almost every description, his knowledge rarely failed. He had high feelings of honour and integrity, and was much esteemed by his professional brethren. He was a warm and attached friend to many, who will greatly feel his loss; and he was a most affectionate, dutiful, and generous son and brother. The bereavement to his aged and respected mother and his surviving brother and sister is indeed very severe, and they will meet with the deep sympathy of every friend.

He was a regular attendant at the meetings of the Institution, frequently taking part in the discussions, and always displaying great anxiety for the welfare of the Society.

MR. JAMES BREMNER was born on the 25th September 1784, at Keiss, parish of Wick, county of Caithness, and was the youngest of a family of nine children, six of whom died in infancy. His Father was a man of great physical strength, uncommon energy of character, and high moral principle, who exerted considerable influence in the district, till his death, which took place at an advanced age, after a prolonged service in the defence of his country. During the absence of the Father on foreign service, young James was with his mother at Keiss, and obtained such an education as her means afforded. He left school at about the age of fourteen, and then had a robust constitution, with a good deal of the rover and adventurer about him. Among the crags and rocks of the district, none were half so venturous; fear was not in his vocabulary; and on one occasion he was found paddling himself through Sinclair's Bay, sitting in the bottom of a large tub! This characteristic determination lasted him through life, and when in his prime, he is believed not to have known what the sensation of fear was. The temporary settlement of his Father at Fort George, took young Bremner there, at the age of fifteen. Here he became a favourite with Colonel Macdowal, who one day asked him whether he would like to join the army, or the navy; to which

he replied, "None of the two;" but added, "that he would like to learn shipbuilding, and that his Father intended sending him to Leith for the purpose." Subsequently, at the recommendation of Colonel Macdowal, he was received as an apprentice, in 1798, in the yard of Messrs. Robert Steele and Sons, shipbuilders of Greenock, whose extensive establishment and business operations at that port, (then unrivalled in Scotland, in commercial importance, and as the resort of shipping) afforded good opportunities for instruction, both theoretical and practical, as well in the planning and building of large ships, as in the methods of drawing them up, and raising them out of the water, when requiring repair and alteration. To the operations of the last-mentioned process, and to various experiments afterwards tried by himself, Mr. Bremner attributed the early and ardent desire he long felt, of being enabled to discover, some effectual means of abating the labour, and facilitating the progress of building under water. In 1804, some improvements in the harbour of Greenock were commenced, and were watched with interest by Mr. Bremner. After remaining at Messrs. Steele's for about six years and a half, he made two voyages to North America, and had all but arranged for permanent settlement, with the view of commencing shipbuilding, at Pictou; but was dissuaded by his friends.

Public attention was now being directed to the herring fishing. Tempting promises were made by the British Fisheries Society to all who should settle in Pulteney-Town, then just becoming o importance; and Mr. Bremner, in his twenty-fifth year, resolved on commencing business in his native parish, where he eventually occupied the shipbuilding yard for nearly half a century, during which time he built fifty-six vessels, from a ship of 510 tons, to a small sloop of 45 tons. These were almost exclusively built for strangers, and were registered at distant ports; but at the same time he greatly improved the boats used for the herring fishery.

Besides carrying on shipbuilding operations, Mr. Bremner was, on numerous occasions, since 1807, employed in making surveys for, designing, and constructing harbours and piers on the northern and most dangerous coast of Scotland, for an extent exceeding six hundred miles. His first work of this kind is believed to have been in connection with the North, or what is now called the 'Old,' harbour of Pulteney-Town, which was designed by Mr. Telford, in 1803, and was contracted for by Mr. George Burn, in 1806. In the progress of this undertaking, Mr. Burn experienced extreme difficulty, in raising and laying the materials required to found the pier. He thereupon consulted Mr. Bremner, who prepared an adequately sized lighter, or barge, on which he erected a crane, capable of being worked simultaneously on both sides of the barge. Again, in 1807, when the breakwater had been extended, so that at the

lowest ebb of ordinary tides, there was a depth of 5 feet of water, Mr. Bremner undertook the submarine building and foundation of the breakwater heads, which he completed to Mr. Telford's entire satisfaction. These works were finished in 1811, at an expense of £16,400, but the harbour soon became filled with sand, and when, after the conclusion of the continental war, and the consequent lowering of freights, larger vessels were employed, they could only be partially loaded in the harbour, and finished in the bay, by means of boats. This was attended with expense, and risk to lives and property, and led to the erection of the South harbour, in deeper water. The survey for this was made by Mr. Joseph Mitchell, M. Inst. C.E., in 1823, and the contract for the quay, and part of the south pier, was let to Mr. Bremner. In 1825, and again in 1826, he was instructed to extend the pier. In the latter year, he also entered into a contract for building the north pier; building and embanking the jetty; making an opening from the south to the north harbour, and closing in the old entrance; and for completing the harbour. As there were only about twenty-four weeks in the year fit for carrying on such works, Mr. Bremner had all his materials at hand, and during the season of 1827, had men at work night and day; the work was making rapid progress, and would have been closed in by the 20th of September, when, on the 10th of that month, a violent storm arose, which swept away about 100 feet of the pier, down to the level of low water. To prevent the breach from spreading, chain cables were passed round the open end, laid upon the pitching of the roadway, and were securely fastened inwards. This was accomplished in two tides, but in that time the damage which had been done amounted to £5,000. Of these works he presented an account to the Institution.[1]

In 1818, Mr. Bremner designed and superintended the construction of Keiss harbour, situated on the north side of Sinclair's Bay, 4 miles from the south-east entrance to the Pentland Firth. At this work, one individual only, the foreman, amongst all the operatives employed, had been bred to the business of a mason. It was used in an unfinished state from 1821 to 1833, being protected during that period by a rough causeway, and was completed in 1834. During the progress of the works, huge stones from 10 to 40 tons weight had to be moved a distance of two miles. For this purpose, two old fishing boats, 16 tons burthen each, were made tight and impervious to water, and across them two ship's yards, fished with hard wood, were placed. Chains of sufficient strength were passed underneath the stones, with the assistance of long levers to lift them slightly. During fine weather the boats were grounded at low water, on each side of the stone intended to be removed, and the

[1] *Vide* Minutes of Proc. Inst. C.E., vol. iii., p. 115.

chains were passed over the yards and secured, and on the flow of the tide, the boats buoyed up and floated off the materials. Subsequently, being desirous of removing some heavy stones for the repair of Banff harbour, from a part of the coast where boats could not approach, casks were used with great effect.[1] Lewises were inserted in the blocks of stone, chains were passed round the casks and made fast at low water, so that on the rise of the tide, the stones were lifted, and could be towed to any spot that was desired. These casks have also been used at Banff and Macduff to assist laden vessels out of harbour. Four of them gave a lift of 44 tons, and on one occasion a vessel of 100 tons burthen, had a deficiency of 15 inches in her draught of water met by these means.

In the summer of 1835, Mr. Bremner was induced to undertake the reconstruction of Sarclet harbour, which is situated in a most exposed position, about six miles south-west of the Bay of Wick. The breakwater, which for its whole length had been built parallel to the run of the sea, and perpendicular, was twice laid in ruins, and on the last occasion was allowed to remain so for some considerable time. But the local situation was so good, that in 1834, Mr. Gibb, of Aberdeen, accompanied by Mr. Mitchell, of Inverness, inspected the harbour, and Mr. Telford being consulted, plans were drawn for its reconstruction. At this work travelling jib cranes were used; they were fixed at such a height as to be above the reach of the sea in winter storms, and the jibs being 120 feet in length, the whole work was commanded by them. The materials for the sea-walls, were quarried at the Bay of Wick, and were conveyed thence by the means previously used at Keiss. The whole of the breakwater was laid and completed in the summer of 1836.

In the latter year he, with other contractors, gave tenders for executing a harbour at Lossiemouth, the plan of which was found impracticable. The Directors then called upon Mr. Bremner to furnish plans, and to tender for the execution of the work. Both of these being accepted, the late Mr. Gibb, of Aberdeen, was mutually chosen referee, to see that the work was finished according to the adopted plans and specification. At this place Mr. Bremner caulked and shored the sea-walls on the inside, put gates on the entrance, 70 feet or 80 feet wide, pumped out the water by steam power, and thus laid the entire area dry, and maintained it so for a period of four months, during which time the excavations, which were in rock, were carried on. He had at that work, also, an ingenious system of cranes, commanding a range of 120 feet, by which he lifted the stones for the sea-wall from the quarry, and deposited them in their places in the wall. These cranes were made with travelling carriages, and the long jibs were swung by

[1] *Vide* Minutes of Proc. Inst. C.E., vol. iii., p. 122.

chains. Each crane was proved to be capable of removing a weight of 6 tons to a distance of 240 feet, in little more than 30 seconds. They answered the purpose of abridging labour admirably. After completing Lossiemouth harbour, he built the harbour of Pitullie, near Fraserburgh, and one on the Caithness coast, of which Mr. Joseph Mitchell, M. Inst. C.E., was the Engineer, for whom he had previously built the harbours of Keiss, Sarclet, Cairnish, and Callicott.

Besides these works Mr. Bremner built the harbour of Ham. He designed and superintended the construction of the harbour of Castlehill, the entrance of which he secured by boom gates, capable of being shipped, or unshipped at pleasure. He also secured the harbour of Sandside, constructing similar boom gates at the entrance. He jointly superintended the harbour of Ocumster, in Caithness. He surveyed, and prepared working plans, with detailed estimates, for the harbours of Scrabster, in the bay of Thurso, and the Kirk ebb of Thurso, and for the improvement of the river; also of the harbours of Acherfell, of Portsoy (Banffshire), and of Hopeman (Morayshire); and through Mr. Telford, for the harbours betwixt Cape Wrath and Bighouse (Sutherland), viz., Rispond, Talmine, Kirktoury, Armadale, and Portskerry. He likewise surveyed, and after their completion, preserved, the harbours of Banff and Helmsdale, in Sutherlandshire. He proposed to connect the island of Tongue with the mainland, by an earthen mound, whereby a steam-boat might ply with safety and facility, and he designed four passage-boat piers, for the ferries of Loch Erribol and Tongue.

Mr. Bremner, from long experience, had arrived at the conclusion, that the surveys for intended harbours should be made, when the liability of the intended buildings to the ravages of winter storms could be observed, and the power required to be provided for defence, could be ascertained. The currents and tides, and their influence on the bottom, particularly when near an estuary, or the mouth of a river, should be carefully noted, and the liability of the formation of banks, or bars, as at Shields, Aberdeen, Ayr, Lossiemouth, &c., with the view of ascertaining how the latter might be remedied. His objections to diving-bell operations were, that they could only be carried on for a short period of the year, that they were liable to serious interruptions from the weather, and that, on such occasions, the work was left exposed. The hearting of the works was frequently washed out, during storms, and the face work was not supported by timber. The expense of the staging and barges was also a serious item; and, moreover, a diving-bell was barely sufficient for building a single stone at a time, so that there was no power of connecting them properly together. At Plymouth and Dunleary they were only

used for forming the ends of the breakwaters, the rest of the stones being thrown promiscuously together—a mode of construction which might be suitable for an open roadstead, though not for a quay wall, where shipping had to lie abreast. He always considered it a bad practice to protect the feet of walls, by throwing down large stones for a width of from 20 feet to 30 feet, as it prevented the approach of vessels. He devised a method of constructing harbours, breakwaters, and other buildings, in deep water—for cleansing harbours, and for raising sunken vessels and other property, of which he has given a minute account, in a treatise published in 1845.[1]

His system consists in building in what he terms 'flotations,' or caissons, framed with transverse beams, during the winter months, but instead of caulking them from without, as is the ordinary practice, he recommends their being caulked from within. These caissons are then to be taken out for deposit, and when over the site of the intended work, the caisson and its appendages are to be disengaged, and according to the nature of the foundation, whether hard, or soft, the inside bottom planking was proposed to be in part, or altogether removed, leaving only the transverse bars, which it is presumed would bind the wall together.

But Mr. Bremner's greatest talent was evinced in the raising and recovering of wrecked vessels, in the wide circuit betwixt Aberdeenshire and the Isle of Skye; comprehending the islands of Orkney, Shetland, and Lewis, and the critical navigation of the Pentland Firth. On these occasions his kindness to the crew and officers was very marked, and he has been known to keep them for months in his own house. He raised not less than two hundred and thirty-six vessels, many of them sunk in a depth of 12 fathoms. His first anxiety was to ascertain the size of the vessel, the position in which she lay, or was sunk,—the nature of the bottom,—whether rock, shingle, or sand; and the description of the ship's cargo, if loaded. He always kept ready six sets of portable machinery, each capable of being conveyed in double carts. The first operation was to bind the ship together, by double, or triple chain purchases, and to endeavour to force the stern of the ship inward and her bows to the sea. The cargo was then discharged early in the following spring, placed on rafts and drawn beyond the reach of breakers. In this way, in 1825, he extricated the cargo of the ship 'Orion,' of Pillau, wrecked at Watersound, on the east side of Orkney. The cargo consisted

[1] *Vide* "Treatise on the Planning and Constructing of Harbours in Deep Water, applicable to the deepening and clearing of rivers for navigation; on Submarine Pile-driving; the Preservation of Ships stranded; and raising of those sunk at sea; on principles of lately-patented inventions." By James Bremner. Tract, 8vo., Plates. Wick, 1845.

of timber, which together with the whole wreck of the ill-fated ship, he carried off by a single raft. On this raft he constructed paddles, wrought by manual labour, with five sheer poles, on which he rigged the courses and topsails of the 'Orion.' In this state he traversed upwards of one hundred miles, through the dangerous navigation of the Pentland Firth, at the rate of three miles and a half per hour, and reached his ship-building establishment at Pulteney-Town in safety.

When a ship was in ballast, his plan was to remove the ballast forward to the bows, and by a purchase aft to get the bows directed to the sea. When the weather moderated, the ballast was discharged, the ceilings were caulked, and bulk-heads were put in, if near to a place of safety. If the hull was damaged, and the sea-beach was flat, he raised her by means of dumb craft and bilge-weighs, and shored her in such a way that the ship could not slip, or fall out of the cradle, either on being hauled up, or launched.

The ship 'Uncertain,' of Sunderland, laden with coals, was only 6 months old, when she struck on a sunk rock, at Broad Bay, near the Butt of Lewis, and lay there in 11 fathoms water, exposed to all the force of the Atlantic Ocean for upwards of two years. Three persons had endeavoured to recover her, but failed. Mr. Bremner effected the object by using five vessels, with twelve floating casks. Four balks of timber, each 60 feet in length, were laid across each pair of vessels; chains were then attached to these balks and to the casks, and at low water they were made fast to the ship to be raised. On the rise of the tide the casks and the vessels each bore a proportion of the weight, and notwithstanding the exposed situation, the ship was carried to the shore in safety. She was then dried, and a bullock's hide being nailed over the leak, she was navigated to Stornoway, where she was thoroughly repaired.

Numerous instances could be mentioned of ships of 500 to 700 tons burthen sunk and fixed in quicksands, being recovered by means of platforms. In 1828, the brig 'St. Nicholas,' of St. Petersburg, was stranded during low-water and ebb tides, in Sinclair's Bay, and sunk 7 feet deep in quicksand. There was a quantity of Russian iron in her hold, under some deals. On the flow of the tide, the buoyancy of the timber, with the violence of the sea, occasioned a separation at the ship's floor-heads, and the whole of the vessel and cargo became engulfed in the sand. Mr. Bremner then planned a long triangular machine of solid balks of timber, with a caisson in the centre, and having strongly hinged scrapers attached to the bottom, to act upon the wreck. Then by means of large iron swivel hooks, attached to long poles, and worked from a stage, the pieces of iron were succes-

sively fished up and raised, and thus 57 out of 60 tons were recovered.

He was employed with one of his sons in assisting to secure, and ultimately in taking the 'Great Britain' off the strand, at Dundrum Bay, in August 1847, after that vessel had been unfortunately run ashore during her first voyage.

For the last twelve years of his life, Mr. Bremner acted as agent at Wick for the Aberdeen, Leith, and Clyde Shipping Company, and in conducting the business of that agency he was frequently placed in positions of danger, from which he narrowly escaped with his life.

Mr. Bremner married early, and his marriage was a happy one in every respect. He had a numerous family, and the sons were all brought up as Engineers. One of them, David, who was Engineer for the Clyde Trustees, a young man of great promise and attainments, and of high moral principle, died four years back, and his Memoir is published in the Minutes of the Institution.[1]

Considering his education and his general career, Mr. Bremner must be regarded as a very extraordinary man. He had a natural perception for marine work, and no Engineer was more successful in constructing piers to withstand the heavy storms of the northern coast. He had a wild and struggling life, but died leaving considerable property for an inhabitant of so northern a locality as Wick.

During the whole of his ship and harbour building career, he was the same impulsive, impetuous, dashing individual. Nothing daunted him. No physical exertion was too much for his herculean frame. He has been known to stand, dripping wet, for two tides in succession, for hours up to the knees in water, without being even hoarse afterwards; and as for frolic and public spirit, his equal was not to be found in broad Scotland.

Mr. Bremner was elected a Corresponding Member of the Institution on the 12th of February, 1833. He received a Telford Medal, in 1844, for his Papers 'On Pulteney-Town Harbour,' 'Sarclet Harbour,' 'A new Piling Engine,' and 'An Apparatus for Floating large Stones for Harbour Works.' He was a contributor to the Great Exhibition of 1851, and received honourable mention "for his models of various apparatus for working in situations exposed to the sea, and of that used to assist in getting off the 'Great Britain' steam-ship," included in Class 7, of which Mr. I. K. Brunel, V.P., was the Reporter.

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[1] *Vide* Minutes of Proc. Inst. C.E., vol. xii., p. 148.

MR. JOHN CHISHOLM, born in the year 1777, was a nephew of the late Mr. Thomas Simpson, of the Chelsea Water-Works. He was brought up as a practical millwright, and was remarkable, in early life, for his skill both as a workman and as a draughtsman. He was a man of herculean frame, possessed of strong natural ability, and had a most retentive memory; whilst decision and integrity were prominent features in his character. After remaining some time in the employment of his uncle, he went to Lancashire, at a period when the millwrights held almost undisputed sway over mills and machinery. There he added greatly to his practical acquirements, and on his return to London became a member of the old millwrights' society. Subsequently he accepted employment under the late Mr. Rennie, who, a few years later, recommended him for the situation of Resident Engineer of the Londonderry Water-Works, the duties of which he performed in a very satisfactory manner, attending at the same time to other important works, including a large flour mill, which he constructed under Mr. Rennie's able direction.

In the year 1812, he was, at Mr. Rennie's recommendation, appointed by the Government to construct the water-works at Cape Town, Cape of Good Hope, which, with the exception of a brief period, during Sir B. D'Urban's governorship, ever after remained under his direction. He also entered into general practice in the colony, and the late Lord Charles Somerset, when governor, entrusted him with some important works, including the laying out and making of the road from Cape Town to Simon's Town, the construction of water-works at Simon's Town, at Government House, Newlands, as well as at several other places.

Mr. Chisholm's death occurred, in August 1856, at his residence in Cape Town, in the 79th year of his age. He was much and deservedly esteemed and regretted in the colony, but his long and continued residence abroad did not enable him to enter into the proceedings of the Institution, which he joined, as a Member, in the year 1843.

MR. SAMUEL CLEGG, jun., was born in Westminster, on the 2nd of April, 1814, and died, at Putney, on the 25th of July, 1856, in the 43rd year of his age. He was the only son of Mr. Samuel Clegg, so well known in connexion with the history of gas lighting. His general education was received under private tuition, while his professional studies commenced by attending the classes at University College, London, and were continued under his Father.

In 1831, before his pupilage had expired, he was placed with the late Mr. Hugh M'Intosh, who employed him in drawing and in taking out quantities for contracts, on the London and Birming-

ham, and on the Greenwich Railways. On the latter line he performed the ordinary services of an Assistant Engineer, and made himself well acquainted with the methods of forming artificial foundations, and the execution of brick-work.

In 1836, he accompanied his father to Portugal, where he assisted in erecting a new mint, at Lisbon, for the Portuguese Government, and was also employed in surveying, in taking levels, laying out lines for new roads, and in making a trigonometrical survey of part of the Algarves.

In January 1838, he was engaged as an assistant in laying the permanent way of the Great Western Railway, between Maidenhead and Paddington. On leaving this work, Mr. John Braithwaite, M. Inst. C.E., employed him in making drawings and getting out the quantities for portions of the Eastern Counties Railway, and entrusted to him the superintendence of several portions of the work. He left Mr. Braithwaite after the completion of the line to Colchester in 1842. About this period he wrote and published "A Practical Treatise on the manufacture and distribution of Coal Gas,"[1] and also the "Architecture of Machinery,"[2] the object of the latter being, as stated in the Introduction, "to inquire into the reasons of error, and to endeavour to point out certain rules for design, by attention to which the many irregularities in construction and form so constantly met with in machinery are to be avoided, and to explain the correct principles of taste."

Towards the close of the same year, he went out to the West Indies, and was engaged in making observations on the working of the engines on board some of the West India Royal Mail Company's vessels, and on other engineering works. He returned home in May 1843, and then went to Lisbon, where he was engaged for a year in negotiating for a Government concession for a public company.

On his return home, in October 1844, he was employed by Captain Moorsom (M. Inst. C.E.) to make the survey for the Waveney Valley Railway, and in assisting the progress of the bill for that railway, through the standing orders committee of the House of Commons.

In July 1845, Mr. Clegg received the appointment of Resident Engineer on the Southampton and Dorchester Railway, a single line 62 miles in length. After the completion of that line he commenced general practice on his own account.

In 1849, he was appointed Professor of Civil Engineering and Architecture, at the Putney College, a post which he filled satisfactorily and efficiently until the dissolution of that Institution.

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[1] *Vide* "A Practical Treatise on the Manufacture and Distribution of Coal Gas." By S. Clegg, Jun. 4to. Plates. (Weale) London, 1841.

[2] *Vide* "Architecture of Machinery; an Essay on Propriety of Form and Proportion." By S. Clegg, Jun. 4to. Plates and Cuts. (Weale) London, 1842.

In the same year he was also appointed, by the commanding officer of the Royal Engineers, at Chatham, Lecturer on Civil Engineering to the officers of the East India Company's Engineers, studying at Chatham. This post he filled until his death, to the entire satisfaction of the authorities. In the year 1855, one of the commanding officers of the Royal Engineers, gave him the following testimonial:—"Seven years back, when I was director of the Royal Engineers' establishment at Chatham, and it being necessary to appoint a highly talented and experienced Civil Engineer, to lecture on Civil Engineering to the officers of the East India Company's service, I selected out of many highly gifted gentlemen, Mr. Samuel Clegg, jun., C.E., merely on account of his superior merit, as he was then wholly unknown to me, except by reputation. On my recommendation he was appointed by the Court of Directors, and has continued ever since to hold that office. Mr. Clegg was an admirable lecturer, and evinced consummate ability, and I have, from an experience of him during several years, a very high opinion of his qualifications."

The great range of subjects embraced in these lectures attest his indefatigable research; they not only included every branch of Engineering as practised in this and other countries, but also lectures on the history and various styles of architecture, together forming a valuable and important mass of information.

In 1851, Mr. Clegg was engaged as one of the annotators of the Official Catalogue of the Great Exhibition of that year.

In 1853, he produced a second edition, considerably enlarged and improved, of his work on the "Manufacture of Gas."

In the spring of 1855, Mr. Clegg was selected, by the Colonial Office, to proceed to Demerara, to report upon the defects of a sea-wall there, and to direct and superintend the necessary works for its restoration. Having satisfactorily performed this duty, he returned home in the autumn of the same year, when, shortly afterwards he was seized with the first attack of the painful disease which, after severe suffering, eventually terminated his existence. He recovered, however, partially from this attack, but a series of relapses following closely on each other, one at last proved fatal. The obstinate character of the disease was attributed by the medical men partly to the effect of the climate, and partly to over exertion in the performance of his duties.

Mr. Clegg was elected a Member of the Institution in the year 1848. He contributed to the proceedings a 'Description of the Great Aqueduct at Lisbon, over the Valley of Alcantara,'[1] for which he received a Walker Premium of Books, and a Paper 'On Foundations, Natural and Artificial,'[2] for which he received a Telford Medal.

[1] *Vide* Minutes of Proc. Inst. C.E., vol. i. (1841), p. 138.
[2] Ibid., vol. x., p. 317.

Amongst other works, upon which Mr. Clegg was engaged at the time of his death, was a project for removing the whole of the manufacture of gas from the Metropolis, by the establishment, at a distance below London, on the Essex shore, of a manufactory of gas, commensurate with the wants of the whole of the various London companies. From these works the gas was intended to have been delivered to the works of the present companies, at a price, it was believed, less than the present cost of production, and thus, without interference with the vested interests, or the free action of the several companies, in the distribution to their customers, a great public benefit would have been secured. A similar system is in progress of adoption by law in Paris, and it is not improbable that, sooner or later, such an improvement will be introduced in London. Mr. Clegg left behind him complete surveys, plans, and calculations on this subject, and though he has not been spared to take part in so great an undertaking, it is hoped his labours in this matter may yet be rendered available, and that his memory may some day be associated with the accomplishment of so important and so beneficial an object.

He was an amiable man, of considerable ability, acquirements, and cultivated taste; and his decease, which was deeply regretted by a large circle of friends, was an irreparable loss to his widow and young family.

MR. GEORGE HADEN was born at Handsworth, near Birmingham, on the 23rd of July, 1788. He received his education at a school at that place, and at an early age worked in several of the manufactories in that neighbourhood, changing as he became acquainted with the system at each, for the purpose of acquiring a general knowledge of the various branches of manufacture. The information thus acquired, he found extremely useful to him in after-life. At Sir Edward Thomason's manufactory, he by accident saw a machine, and, from memory, made one so exactly like it, that he was supposed to have been employed by some party to pirate the invention; but, on explanation, it was found that he had constructed it entirely at his own house, and for his own amusement. This firm, perceiving his ingenuity, wished to retain his services, but he preferred Engineering, and was, therefore, apprenticed to Messrs. Boulton and Watt, of Soho, in whose service his father, (who is honourably named in Mr. James Watt's will as an "honest man,") had been for many years employed, chiefly in the superintendence of the copying-machine business. His energy during his apprenticeship, was very marked. At that time the late Mr. Brunton was manager of the engine-works, and if he wanted any little matter schemed and fitted up, young Haden was generally employed upon it, and he never hesitated to work all night, and would not leave it

until it was completed, frequently working during three nights in a week. On the completion of his apprenticeship he was employed by the firm, first at Manchester, whence he was sent for as "the young man that was never tired;" and for them he also erected the first gas-works established in Leeds. He afterwards went to Glasgow for the same firm, where he remained five years, engaged in erecting the Cranston hill Waterworks, since removed, being the first in Glasgow. He was also engaged in erecting the first pair of engines that worked together, at right angles, on board a steam-boat, the 'Princess Charlotte,' on the Clyde. They were two 4 HP. engines, and were intended to work each paddle separately, but Mr. Haden connected them. He subsequently erected many engines in Glasgow, Edinburgh, and the neighbourhood; and, in the pursuit of his calling, he was so indefatigable and industrious, that Mr. James Watt at one time doubted whether he could have been occupied so many hours as were stated; but after examining the books, and seeing what was done each day and night, Mr. Watt expressed himself as perfectly satisfied, and returned the books, with a present in addition to the overtime. One incident will serve to show the active and persevering character of the man. On being sent for to repair an engine, fifteen miles from Glasgow, he rode over, on horseback, in a storm of sleet and snow. He at once took out the piston, when he found a leak in the bottom of the cylinder, and as the cylinder was too hot to stand in, he was suspended for twenty minutes, head downwards, repaired the leak, started the engine, and returned immediately to Glasgow.

On his return to England, he settled at Trowbridge, and was appointed, by Messrs. Boulton and Watt, their agent in the West of England, including the counties of Gloucestershire, Wiltshire, and Somersetshire, where he erected a great number of steam-engines for the cloth-manufactories: this engagement continued for thirty-four years, and after its expiration, he continued to practise on his own account, taking out patents, for improvements in the machinery for the manufacture of cloth. One of these had reference to the dressing machinery, which, by an ingenious system of revolving steam cylinders, on a revolving barrel, gave a high lustre to the broad cloth. Another was for changing the usual gig barrels to certain angles while in rotary motion. A third was for causing the boards and brushes to move horizontally during the revolving motion of the cylinder itself. During this period his attention was drawn to the ventilating and warming of buildings of all kinds, a department of the profession which he followed with great assiduity, and in which he attained a good reputation, being intrusted with many large buildings in all parts of the country. He was much engaged with the Commissioners of Prisons, for

whom he designed many works, having a patent for apparatus specially applicable to such buildings.

Mr. Haden possessed great decision of character, and from his long practical experience, had gained an extensive acquaintance with all kinds of machinery, his views on mechanical subjects being remarkably clear-sighted. He was deservedly respected by all who employed him, or who served under him, as being a man of strict integrity and honesty of purpose, and who was always desirous of promoting the interests and well-being of others. He was frequently engaged in arbitrations, and was often selected to act as umpire. He was, during the whole of his life, especially anxious for the welfare of the young, and for thirty years took the active superintendence of a large Sunday-school. Frequently in his journeys in different parts of the kingdom, he met, and received the grateful thanks of those who, in early life had been his pupils, and who had profited by the instruction imparted by him and the discipline he enforced. However great his labours and exertions might have been during the week, he never neglected this work on the Sabbath-day. He was a steady promoter of the education of the people, and all liberal and philanthropic measures were ever supported to the best of his ability, displaying in this the spirit of a Christian philanthropist. As a father he was kind in manner, but firm in discipline, and his decease, which occurred on the 29th of October, 1856, in the sixty-ninth year of his age, left a blank in the family-circle which cannot be replaced.

His remains were followed to the grave by a large number of the members of the local Mechanics' Institution, of which he had always been a liberal supporter, and by many Sunday-school teachers. The local Advertiser, in alluding to his death, says: "In the decease of Mr. Haden, science has lost an able engineer, society a useful member, and the poor a generous and sympathising friend. Independently of the benefits he afforded the town from the number of men he employed, and the productions of skill he sent all over the globe, he was always ready to lend a helping hand to any good work. * * * He was religious without sectarian bigotry—liberal without ostentation."

At a special meeting of the Committee of the Mechanics' Institution, the following resolution was passed: "That the Committee of the Trowbridge Mechanics' Institution (on behalf of themselves and the other members of the Institution) have heard with deep regret of the death of Mr. George Haden, their late President, benefactor, and friend; and in expressing their sympathy with the surviving son and other relatives, they cannot but feel, that it must be an alleviation of his and their sorrow, to reflect that the life of the departed was devoted to piety and benevolence; and that, as the promoter of every good object, the special friend of the working-

classes, and the kind instructor and guide of the young, his name will be cherished, his actions live, and his example be followed when marble monuments have crumbled into dust."

He had been a Member of the Institution of Civil Engineers for twenty-two years, having joined it in 1834, and he always took a lively interest in the proceedings, but his constant residence in the country prevented his frequent attendance at the meetings.

MR. CHARLES RAMMELL was born on the 4th of February, 1822, at Street, in the Isle of Thanet, and was educated at an academy, near Margate, where he was articled, in 1837, to Mr. William Edmunds, an Architect and Surveyor of considerable local eminence. In 1842, he entered the office of Messrs. Grissell and Peto, in London. In 1844 and 1845, he was chiefly engaged, under Mr. Bidder, (V.P. Inst. C.E.) in laying out various lines of railway, and particularly, the North Staffordshire line. From 1846 to 1849, he was employed, as Resident Engineer, in superintending the execution of a considerable and difficult portion of that railway, from the junction with the London and North-Western line, at Macclesfield, to the tunnel at Harecastle. In 1851, he was appointed by Mr. Robert Stephenson, M.P., President, and Mr. Bidder, V.P., to survey a line of railway of about 60 miles in length in Norway, connecting Christiania with Lake Miösen, and of this line he had the entire local charge of the execution, up to its completion, at the latter end of 1854. On the 20th February, 1855, he started for India, where he had charge, for a few months, of some engineering works up the country, in connection with the great line of railway communication between Calcutta and Bombay. He subsequently accepted an engagement to survey the proposed Euphrates Valley Railway, and left Bombay early in June, 1846, for the Euphrates, intending to examine minutely the route through Asia Minor and to Constantinople, and thence to proceed homewards to report the result of his labours. Unfortunately he entered upon this arduous task, at a season of the year which, as he well knew, greatly increased its dangers, and when he reached Bussorah, he was suddenly carried off, by an attack of illness, brought on by the excessive heat then prevailing, the thermometer constantly standing above 100° Fahrenheit, without a breath of air, even at night. Although complaining of general uneasiness, he did not think the state of his health such as to cause him to seek advice, but had recourse to the contents of his medicine chest, chiefly for tonics and stimulants, with a view of averting, if possible, an attack of Bussorah fever, about which he had received some directions in Bombay. On the morning of the 12th of June he had employed himself in writing letters to his friends, and, very soon afterwards,

he was seized with giddiness, followed by bleeding at the nose, an other serious symptoms, and within two hours he expired, at the house of the British vice-consul, at Maghill, near Bussorah, where he had only arrived five days previously. The immediate cause of death was ascribed to a suffusion of blood on the brain, during an apoplectic fit. On the following day his remains were buried in the garden behind the Residency. His premature decease at the age of thirty-four, was deeply regretted by his friends, as well as by all those Engineers with whom he had been associated, his cheerfulness and ready co-operation rendering him a general favourite. He joined the Institution, as a Member, in the year 1855, but his provincial and foreign engagements prevented his taking any active part in the proceedings at the Meetings.

MR. JOHN URPETH RASTRICK was born at Morpeth, in the county of Northumberland, on the 26th day of January, 1780. He was the eldest son of Mr. John Rastrick, who was an engineer and machinist of great ingenuity, principally employed in the construction of weirs, mills, and bridges, on the mountain streams of the neighbourhood. He claimed the invention of the treadwheel for prisons, and it is possible, that he may have designed a similar machine, before it was introduced by Mr. (now Sir William) Cubitt, to whom the invention is with strict justice ascribed. At the age of fifteen, young Rastrick was articled to his Father. At this period he was remarked among his associates, for the possession of great energy of purpose, untiring perseverance, clearness of intellect, and sound mechanical and mathematical knowledge. At about the age of twenty-one he went southward, to gain experience as a machinist and millwright, particularly in the introduction of cast iron for machinery, then almost in its infancy. He remained for some time at the Ketley Iron Works, in Shropshire, and soon after entered into partnership with Mr. Hazeldine, of Bridgnorth, as a mechanical engineer, taking special charge of the iron foundry.

During this partnership, Mr. Rastrick continued to practise, on his own account, as a Civil Engineer, and in the years 1815 and 1816, he built the cast-iron bridge over the river Wye, at Chepstow, which was opened on the 24th July, 1816. The centre arch of this bridge had a span of 112 feet, and a versed sine of 13 feet; the arches on each side of the centre arch were 70 feet span and 10 feet 9 inches rise; and the two side arches had each a span of 34 feet, with a versed sine of 7 feet 3 inches. Economical considerations necessitated the use of part of the foundations of a former bridge, which somewhat interfered with the general symmetry of the appearance of the new bridge; and the immense rise of tide, (48 feet,) and its great rapidity, rendered it a work of no ordinary

class. The extreme lightness of the cast-iron work of this bridge, and its general details, are remarkable, and rival those of works of more recent construction. Several smaller bridges were also cast and erected in Shropshire under his direction.

On the death of Mr. Hazeldine, about the year 1817, Mr. Rastrick became the managing partner in the firm of Bradley, Foster, Rastrick, and Co., iron-founders and manufacturers of machinery, at Stourbridge, Worcestershire, taking the principal engineering part in the design and construction of rolling-mills, steam-engines, and other large works. At this time he designed and executed many extensive iron works in the Midland Counties, particularly those at Chillington, near Wolverhampton, and at Shut End, near Stourbridge. He was also consulted as to the alteration and extension of many works in Wales.

In January, 1825, Mr. Rastrick was engaged by the promoters of the Liverpool and Manchester Railway, along with Mr. George Stephenson, Mr. Sylvester, Mr. Brunton, Mr. Philip Taylor, Mr. W. (now Sir W.) Cubitt, Mr. James Walker, Mr. Nicholas Wood and others, to visit the different collieries in the North of England, with a view of experimenting and reporting upon the tramroads, and engines at work upon them. For this purpose a series of experiments was made with the locomotive engines on the colliery tramways at Killingworth and Hetton. In the following April, when the Bill for the Liverpool and Manchester Railway was before Parliament, he was the first engineering witness called by the Company, in support of their case, which, it will be remembered, was most vehemently opposed by the Canal Companies. On that occasion he stated, that, ten, or twelve years previously, he had made a locomotive engine, for Mr. Trevithick, to run upon a circular railway, but that it was quite capable of being applied on an ordinary railroad; also, that two years before, in 1823, he had seen one at work at the Middleton Colliery, near Leeds, which had a cog wheel, working into a rack rail, at the side, on Blenkinsop's system. The evidence he gave, to show the powers, advantages, and safety of the locomotive engine, contributed materially to the ultimate successful issue of that remarkable case. The clear and scientific character of his evidence firmly established his professional reputation, and from that time he was employed to design, or to support in Parliament, a large proportion of the principal lines of railway in the United Kingdom.

In the years 1826 and 1827, he constructed a line of railway, about sixteen miles in length, between Stratford-on-Avon and Moreton in the Marsh. This line is believed to have been the first that was laid with wrought-iron rails, manufactured under the patent of Mr. Birkenshaw, of the Bedlington Iron Works, in Northumberland. Horse power only was used, which is the case

to this day. In 1828-29, he constructed the Shut End Colliery Railway, from Kingswinford to the Staffordshire and Worcestershire canal, a distance of three miles and an eighth. This line was opened on the 2nd of June, 1829,[1] with a locomotive engine, built under Mr. Rastrick's superintendence. This engine had two, or three flues in the boiler, and, in economy, speed, and accuracy of workmanship, equalled, if it did not excel, any engine that had been hitherto produced. He also constructed one of the very early locomotives sent from this country to the United States.

When the Liverpool and Manchester Railway was approaching completion, the Directors had to take into consideration the power to be employed upon it, and they soon arrived at the conviction, that horse power was totally inapplicable. The real question was thus reduced to the relative merits and capabilities of fixed and locomotive engines, both of which systems were in use at the time. To determine this point Mr. Rastrick and Mr. James Walker were requested to proceed to Darlington, and the neighbourhood of Newcastle, to inspect the different railways in those districts, and to ascertain, by a thorough investigation into the power of the engines, the cost of working them, and their actual performance, the comparative merits of the two descriptions of moving power. They made separate reports,[2] but both agreed in the opinion, that the locomotive engine, as then known, was not equal to the stationary system, which they recommended the Directors to adopt. As, however, some of the Directors had a feeling in favour of the locomotive, in April, 1829, a premium of £500 was offered for the best locomotive engine, subject to certain conditions and stipulations. The 6th of October of the same year was fixed upon for the trial, and the judges appointed were Mr. Rastrick, with Mr. N. Wood and Mr. Kennedy. The reward, as is well known, was in favour of the 'Rocket,' constructed by Mr. Stephenson, in which were first combined Mr. H. Booth's multitubular boiler, with the exhausting action of the blast-pipe. Subsequently, Mr. Rastrick, in conjunction with Mr. Hartley, made experiments on three descriptions of carriages, with a view of ascertaining their comparative amount of friction with outside bearings.

About this time he constructed the short branch of the Liverpool and Manchester Railway, from Kenyon to Leigh.

In the year 1830, he was engaged with the late Mr. George

[1] An account of the opening of this railway, and of some experiments to test the power of the locomotive engine, is given in the "Mechanics' Magazine," vol. xi. (1829), p. 301.

[2] *Vide* "Liverpool and Manchester Railway.—Reports to the Directors on the Comparative Merits of Locomotive and Fixed Engines, as a Moving Power." By James Walker and J. U. Rastrick, Esqrs. 8vo. Liverpool, 1829.

Stephenson, in surveying and determining the course of the line from Birmingham to join the Liverpool and Manchester Railway, afterwards called the Grand Junction, and in selecting a line from Manchester to Crewe. In all the different applications made to Parliament for these lines, Mr. Rastrick was generally associated with Messrs. Stephenson and Locke, until, in 1833, they together succeeded, in carrying the Acts for their respective portions, after a lengthened contest with the Canal Companies and the land-owners. Mr. Rastrick was always consistent in laying down, and advocating, a line of railway as direct as circumstances and the nature of a district would admit. In the case of this particular railway, he took no part in the application made to Parliament in the following year, to vary the line, by which the cost was somewhat diminished, by increasing the length.

In the year 1835, the Manchester and Cheshire Junction Railway was brought forward, and Mr. Rastrick was appointed Engineer. This line was opposed by a competing project, called the South Union Railway, which led to one of the longest and most expensive contests then on record. After two years of parliamentary inquiry, the Act was obtained for the original line, with those which have since been made in conjunction, under the names of the North Staffordshire, and the Trent Valley Railways.

As the advocate of direct railway communication, Mr. Rastrick's aid was sought, in 1836, by the promoters of the direct Brighton line; and co-operating with Sir John Rennie, they together succeeded in carrying that line, against several conflicting projects, in the session of 1837. Towards the close of that year, the active superintendence of the line, including a branch to Shoreham, was confided to him; and the numerous heavy works, comprising the Merstham, Balcombe, and Clayton tunnels, and the Ouse viaduct, near Cuckfield, consisting of thirty-seven arches, and crossing the river at an elevation of 100 feet, were completed by the autumn of 1840. Shortly afterwards he constructed extension lines to Lewes and Hastings, on which the Brighton viaduct is situated, and from Shoreham to Portsmouth, on which, perhaps, the most remarkable work is the drawbridge over the river Arun; also a series of branch lines to Horsham, Newhaven, East Grinstead, Epsom, and other places, which together now form the series of lines known as the London, Brighton, and South Coast Railway.

The other principal railways executed by Mr. Rastrick, were the Kingswinford, the Bolton and Preston, the original Gravesend and Rochester, (a single line along the towing-path of the canal,) and the Ambergate, Nottingham, and Boston, and Eastern Junction line, from the Midland Railway at Colwich to Grantham.

Among the many projects with which he was connected during his long professional career, but which, from various causes, were

not carried out, though the surveys were made, and deposited for application to Parliament, a few of the more important may be named:—

In 1835, a railway from Stourbridge, by Dudley, to Birmingham. In 1838, a ship canal from Lewes to Newhaven; a railway from the London and Brighton Railway, at London Bridge, to Westminster Bridge, called the South Metropolitan; and the West Cumberland Railway, from Lancaster, crossing the Morecambe Bay and Duddon Sands, by Whitehaven, to the Maryport and Carlisle Railway at Maryport. In 1839, a railway from Manchester to Derby. In 1840, railways from Stockport to Macclesfield, and from Leek to Stoke-upon-Trent, and the Birmingham and Stourbridge Junction Canal. In 1841, the East Anglian Railway, from Bishops Stortford, by Cambridge, Newmarket, Mildenhall, and Thetford, to Norwich and Yarmouth. In 1842, a railway from the Brighton Railway, at Croydon, to the South-Western Railway, at Vauxhall. And in 1845-6 the direct London and Manchester Railway.

The Lynn and Ely, and Lynn and East Dereham, Railways (now called the East Anglian), were surveyed under Mr. Rastrick's direction, and the Act of Parliament for these lines was passed whilst he was the Engineer. After the Acts were obtained, he was appointed Consulting Engineer, but shortly afterwards Mr. J. S. Valentine (M. Inst. C.E.) was appointed to carry out the works, which were executed under his sole direction.

As a witness Mr. Rastrick always displayed the greatest shrewdness, as well as coolness, and no amount of cross-examination would induce him to give a hasty, or unconsidered answer. When the Bill for the Liverpool and Manchester Railway was before Parliament, the late Mr. Baron Alderson, then the leading counsel, had baffled many of the railway witnesses, by cross-examination, on the effect that locomotive engines would produce on horses on the public roads. This was before the multitubular boiler was introduced, and it had been admitted, that the chimney might sometimes become red hot.

Similar questions were addressed to Mr. Rastrick, and were thus answered, in a manner to set at rest that style of examination.

Q. "Is not this tube (meaning the chimney) sometimes red hot?—*A.* Yes.

Q. "Would not that frighten a horse?—*A.* I do not think it would, for how is a horse to know it was red hot.

Q. "Then you think if they were to put a red-hot poker to a horse's nose he could not know whether it was red hot or not?—*A.* If it was put so near as to burn him, he would be frightened at it; but if you were to take a thing painted red, and another red hot, he would not know the difference."

Mr. Rastrick possessed great vigour and strong determination of character; opposition and difficulties only roused him to greater efforts. He was a man of unremitting application, and he has been known to devote whole nights, as well as days, to the careful consideration of the details of his works, with an energy and minuteness that would have worn out many of his juniors, upon whom his example produced excellent effect, and he was always regarded by his principal assistants with feelings of the highest regard and respect.

He joined the Institution as a Member in the year 1827, and was also a Fellow of the Royal Society, and a Member of the Society of Arts.

He retired from the active duties of the profession about the end of the year 1847, and died on the 1st day of November, 1856, at his residence, Sayes Court, near Chertsey, Surrey, in the 77th year of his age, and was buried in the new cemetery at Brighton. Although old age had enfeebled his bodily frame, yet he evinced, even up to the last moment of his existence, the same indomitable energy and clearness of intellect, for which he had always been so remarkable.

Mr. JAMES MEADOWS RENDEL was born in the winter of the year 1799, near Oakhampton, on the borders of Dartmoor, in Devonshire. He was the only son of a country surveyor and farmer, and the grandson of Mr. Meadows, F.R.S., a well-known architect of his day. His Father was a man of more than ordinary stature and massive frame, with a very intelligent face; plain in manners, and reserved in conversation, but conveying the impression, that he possessed an excellent judgment and a well-regulated mind; whilst to his mother, who was a woman of considerable acquirements, he owed the rudiments of his early education. He passed his youth in the neighbourhood of Teignmouth, receiving his education at a country school, and being initiated into the practical operations of a millwright, with his Uncle, who resided there, whilst from his Father, who had charge of a district of roads, &c., he obtained a certain degree of familiarity with the rudiments of Civil Engineering.

At an early age he went to London, and obtained an engagement, as a surveyor, under the late Mr. Telford, by whom he was employed on the surveys and experiments for the proposed suspension bridge across the Mersey, at Runcorn. About the year 1822, he settled at Plymouth, and commenced practice on his own account, being then chiefly employed in the construction of roads, in the north of Devon. In September of that year, having designed a suspension bridge for crossing the Tamar, at Saltash, he

came under the notice of the late Earl of Morley. With that quickness which characterized his lordship in all matters of business, he suggested the applicability of the principle to the construction of a bridge across the Catwater, an estuary of the Plym, within the harbour of Plymouth, at Lary. The drawings having been made and approved, an Act of Parliament was obtained in 1823; but in the following year it was repealed, so far as related to the suspension bridge, and the powers were extended, authorizing the erection of the present structure. Lord Morley's penetration enabled him to perceive the powers of the young Engineer, and after satisfying himself, by application to Mr. Telford, of the correctness of his opinion, he intrusted to Mr. Rendel, then only twenty-five years of age, the execution of this work, which he knew to be one full of difficulty and risk. Events justified the soundness of his lordship's judgment; and the generosity with which Mr. Rendel was shielded from all interference, made him feel that, in spite of his youth, entire confidence was placed in him. This was so gratifying to his susceptible temperament, that the anxious superintendence of the works became a labour of love. At that time the communication between the opposite banks was carried on by means of a ferry-boat, which, from its peculiar construction, was called "The Flying Bridge," and had been established by the Earl of Morley, as proprietor of the ancient ferry, between Oreston and Cattedown. The new bridge consisted of five elliptical arches of cast iron, springing from abutments and piers of stone-work. From the loose description of the soil forming the bed of the river, considerable skill was required in securing the foundations of the bridge, from the undermining effects of the current, the rapidity of which was very considerable. This danger was effectually guarded against by Mr. Rendel, by the formation of an artificial bottom extending from 60 feet above to 70 feet below the bridge. In levelling the pile-heads, and paving the spaces between them, in order to make a firm basis for the piers, a wooden diving-bell was used, into which the light was admitted through lenses fixed in the top. The works were commenced in August, 1824; the first stone was laid on the 26th of March, 1825, and the bridge was opened on the 14th of July, 1827. The cost of the works was £27,126. This bridge was, with the exception of that of Southwark, the largest that had hitherto been constructed of iron. Mr. Rendel presented a full description of the works to the Institution: this was published in the first volume of the Transactions,[1] and for it, he received a Telford medal.

Whilst the Lary Bridge was being constructed, an accident oc-

[1] *Vide* Transactions Inst. C.E., vol. i., pp. 99 to 108. Also Trans. of Plymouth Inst., vol. i. (1830).

curred, which proved nearly fatal to Mr. Rendel. He fell off the scaffolding into the sea, and, being encumbered with a heavy coat and jack boots, he was submerged for some time before being rescued. The little glimmering of life that remained was fast being extinguished, by the exposure and injudicious treatment of the bystanders, when, most fortunately, Dr. Cookworthy arrived, and after using protracted efforts, aided by the devices of medical science, he succeeded in restoring the latent spark of life. The most cordial friendship ever afterwards subsisted between Dr. Cookworthy and Mr. Rendel, in which their families participated. An interesting feature of this accident was, that Mr. Rendel, whilst under the water, experienced the most vivid retrospect of every circumstance of his previous life, with a minuteness and fidelity perfectly marvellous.

In the year 1826, Mr. Rendel constructed the Boucombe Bridge, where hydraulic power was first applied to the machinery for working swing bridges. Soon after the completion of the Lary Bridge, he constructed, for Lord Morley, some roads, the Cann Quarry Tramway, and a sluice of peculiar construction at the Chelson Meadows.[1] He also made several turnpike roads, including the southern route between Plymouth and Totness, the road from Plymouth to Cornwall, *viâ* Saltash,[2] and the road from Devonport to Liskeard, *viâ* Torpoint; and in connection with one of these roads, he designed and superintended the construction of a bridge over the creeks, at Kingsbridge.

In the year 1831, he introduced a new system of crossing rivers, by means of chain ferries worked by steam power, and in 1832, a floating bridge was constructed by him on this principle, for crossing the Dart, at Dartmouth. In 1832-34, similar floating steam bridges were established at Torpoint and Saltash, across the Tamar, which have proved of considerable utility to the neighbourhood, by the facilities they afford, for passing to and from Devon and Cornwall. Prior to their establishment, the only means of communication was by ordinary ferry boats; now vehicles, horses, and passengers, are conveyed across without any inconvenience. The account of this bridge was laid, by Mr. Rendel, before the Institution in 1838, and was published in the Transactions.[3] For this the Council again awarded to Mr. Rendel, the Telford Medal, the highest acknowledgement in their power, accompanied by a suitable record, of the sense entertained of the benefit conferred by him on the inland navigation of the country, in overcoming the difficulties of crossing rapid tideways. He afterwards designed

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii. (1842), pp. 62 and 63.

[2] *Vide* "A Report to the Subscribers to a Survey of proposed Turnpike Road from Plymouth to St. Austell." Tract. Folio. Plates. Plymouth, 1835.

[3] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1838), pp. 21—24; and Transactions, vol. ii., pp. 213—227.

bridges of a similar character for crossing the Itchen at Southampton, and for passing between Gosport and Portsmouth. The rapid introduction of the railway system prevented, however, a further development of this useful system of crossing rivers. He was also engaged in the endeavour to establish similar bridges over the river Hooghly, at Calcutta, and about the year 1838, he was consulted as to the feasibility of establishing this description of ferry over the rivern Severn, at Newnham.

During this period, Mr. Rendel was further engaged in examining and reporting upon the improvement of almost every harbour and river in the South West of England, and then acquired that mastery of what is termed hydraulic engineering, on which his fame will chiefly rest. Thus, in 1829, he designed the harbour, which has since been executed, at Par, in Cornwall; in 1835, he designed and carried out works in connection with the Bude harbour, dock and canal; in 1836, he designed the Brixham harbour and breakwater at Torbay,[1] for which an Act was obtained, also works connected with the port of Exmouth, in Devonshire, which latter were executed; in 1836-7, he reported to the Post-office authorities, on the practicability of building bridges across the river Severn at Aust and New Passages; and designed the Millbay Docks, now executing by Mr. I. K. Brunel, V.P. Inst. C.E., as a terminus to the Western railways; in 1837, he designed an extensive harbour at Helston, in Cornwall,[2] and the restoration of Southampton pier; in 1838, a harbour for Poole, in Dorsetshire; and the Gosport dock and pier, the latter of which was executed; in 1840, he designed improvements and new docks in the port of Hull, and reported on the proposed steam-packet harbour and docks at Portsmouth,[3] and on Sir John Rennie's plan for embanking the shores of the Great Wash;[4] in 1841, the harbour of Polpero, in Cornwall, and river walls on the Avon, near Bristol; in 1843, improvements for the port of Harwich, and for Swansea harbour; in 1843-4, he constructed canals in Devonshire, and was engaged on the Colchester and Arundel Navigation; and in 1844, he designed harbour improvements for Newhaven and Little Hampton, in Sussex. During this period he was employed by the Admiralty, and other Government Departments, as well as by public companies, on various matters connected with rivers, harbours, docks and other marine works. In all cases he was engaged

[1] *Vide* "Report and Plans for a Breakwater at Brixham, in Torbay." Tract. Folio. Plates. London, 1836.

[2] *Vide* "Report on the Practicability of forming a Harbour at the Mouth of the Loe Pool, in Mount's Bay, near Helston, in the County of Cornwall." Tract. 4to. vol. xxxiv. Plans. Plymouth, 1837.

[3] *Vide* "Report on the proposed Steam-Packet Harbour and Docks in the Port of Portsmouth." Tract. 8vo. vol. lxxv. Plan. London, 1840.

[4] *Vide* "Report on the Plan of Sir J. Rennie, for Embanking the Shores of the Great Wash." Tract. 8vo. vol. lxxiv. Plan. London, 1840.

professionally, and in none was he the projector. He was also much employed, about this time, by the Exchequer Loan Commissioners, and especially, in 1835-7, in the repair of the Montrose Suspension Bridge,[1] after its fall, where he introduced the principle of trussing the framing of the roadway, which is now acknowledged to be so necessary, to insure the safety of such structures, by preventing the undulation by which so many have been destroyed.

About the year 1838, Mr. Rendel removed to London, leaving Mr. Beardmore, M. Inst. C.E., as his partner at Plymouth. He soon became extensively occupied on important works, and was engaged in the Parliamentary contests of that remarkable period in the history of engineering. The works executed in the neighbourhood of Plymouth about this time, were, from 1835 to 1842, the improvement of the Devonport Water Company's service reservoirs and distributing mains, for the supply of water to the town, the dockyard and the public departments; and in 1841, the construction of the Millbay pier, in a small tidal basin at the top of Millbay, Plymouth. This pier was the precursor of the Great Western Docks, and was a work of considerable difficulty, owing to the great depth of water in which it was built. Here he first introduced the method of construction, since employed with so much success, at the great harbours of Holyhead and Portland.

In 1835-36, he projected several routes through the South of Devon, with the view of extending the Bristol and Exeter Railway to Plymouth. In 1839, he was engaged, at the instance of the projectors, in preparing various schemes for an inland line of railway between Exeter and Plymouth, over Dartmoor, where the character of the district rendered necessary works of considerable magnitude, and demanded great skill and judgment on the part of the Engineer. The funds of the district were, however, insufficient for so large a work, and the railway was afterwards constructed, in conjunction with the Great Western Company, and by their Engineer, Mr. I. K. Brunel, V.P. Inst. C.E.

In the year 1843, Mr. Rendel became connected with the projectors of the Birkenhead Docks, his plans for which, whether they are ever completely executed, or not, will always be remarkable in the annals of engineering, for the praise and condemnation which they have alternately received, as well as for the extraordinary ability and success with which Mr. Rendel defended them, before numerous Committees of both Houses of Parliament, against the united influence of parties both at Liverpool and at Birkenhead.[2] The design for these Docks brought Mr. Rendel

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1841), pp. 122–9.

[2] Since this was written, an Act has been passed, transferring the Liverpool and Birkenhead Docks to a new Trust, representing all parties interested in the

very prominently before the world, and the protracted contests on this subject will not only be long remembered, in the history of Parliamentary Committees, but the evidence given by him and other Engineers, as now collected, forms a valuable record of the state of engineering practice. The almost incessant labour, and the mental anxiety inseparable from this undertaking, were, however, more than even his powerful constitution could support, and it is feared that they tended to shorten his valuable life.

These hydraulic works were followed by many others, and Mr. Rendel has since constructed, in 1844-53, the new docks of Grimsby; in 1848-53, extensions of the docks at Leith, including a new steam-dock; in 1850-53, docks at Garston, on the Mersey, for the St. Helen's Canal and Railway Company; a new junction dock and other works, for the East and West India Dock Company; and a new basin with dock and river entrances of a very large size for the London Dock Company in the Thames (now in progress). With regard to the Grimsby Docks, it should be remembered, that the works were projected far out upon the mud banks of the river Humber, entirely beyond low-water mark,—that great difficulties were encountered in laying the foundations, owing to the treacherous nature of the substratum,—that the dock walls were executed in a novel manner, and yet, notwithstanding, the whole works were most successfully accomplished. Here, Mr. Rendel led the way in the application of the comprehensive system of hydraulic machinery, for working the lock-gates, sluices, cranes, &c., invented by Mr. W. G. Armstrong, M. Inst. C.E. For this work he received a Grand Medal of Honour from the Paris Universal Exhibition, of 1855. In a discussion at the Institution, in 1849,[1] on the preliminary works for these docks, Mr. Rendel thus expressed himself, as to the profession of an Engineer:—

"He was well aware how much Engineers had to learn, and how valuable an accurate knowledge of geology must be to them; but he assured the Reverend Dean (of Westminster, Dr. Buckland,) that, as a body, they were not so ill-informed as had been assumed, and that those who were anxious for the success of their works, adopted more precautions than he appeared to be aware of. They fully appreciated the necessity of a knowledge of geology, and although they might not be able to discourse upon it, with the eloquence of a Buckland, a Lyell, or a Sedgwick—to prosecute a

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Mersey. A clause of this Act enacts that the works as designed by Mr. Rendel, and authorized by Parliament, shall be executed in the shortest possible time. Mr. Rendel's decease having taken place prior to the passing of this Act, the credit of this particular clause belongs, mainly, to the exertions of Mr. Brunel, (V.P. Inst. C.E.), acting on the part of the Great Western Railway Company.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., pp. 1 to 23.

microscopic investigation, with the discrimination of Owen, or Mantell, or to speculate so plausibly on the events of past ages, as were those eminent professors,—no careful Engineer decided upon the position, or mode of construction, of his works, without a series of trial borings, a careful examination of the specimens, and experiments upon them, with a view to ascertain their properties, and their capability for sustaining weights. Instead of accusing Engineers of knowing so little, it was rather a subject of surprise that they knew so much, when it was considered how much they were required to mix in the active business of life; and he considered that no other profession demanded such varied acquirements, or the exercise of such general common sense and judgment."

He also reported on and examined, at various times, most of the principal docks in the kingdom, including, amongst others, those at Cardiff, Hartlepool, Sunderland, and the Victoria (London) Docks.

About the year 1844, Mr. Rendel was engaged on the Edinburgh Water Works, and from 1846 to 1852, he acted as Consulting Engineer for the Company. The works of the extensions were executed under the immediate direction of Mr. J. Leslie, (M. Inst. C.E.). In 1853, he reported to the Corporation of Leeds, on the supply of water to that borough, and suggested plans for its improvement.

In the year 1845, he was employed, with other Engineers, by the Admiralty, in reference to the great Packet and Refuge Harbour of Holyhead, and his plan being selected, he was intrusted with its execution. In 1846-7, he constructed a graving dock at the old harbour there. In the year 1847, he was also intrusted with the Harbour of Refuge, at Portland. Both these works have hitherto progressed in the most rapid, successful, and gratifying manner; and even if he had done little more, they alone would suffice to hand down his name to posterity, beside those of Smeaton, Rennie, and Telford. They were conceived with the largest views. In both cases the system adopted was to deposit the masses of stone, of all dimensions, vertically from railway waggons, running on fixed timber staging, instead of employing the old system of dropping the stone from barges, or of running out a bank from the shore, and tipping the materials over the end and sides, allowing the waves to impinge with all their force upon the mass, before it had time to become consolidated. By this new system the mass was brought up simultaneously, to above the level of the sea, the utmost force of which it withstood with ease. In this manner, as much as 24,000 tons of stone have been deposited in one week, whilst to supply this vast demand, monster blasts of 5, or 6 tons of gunpowder were frequently employed. It is worthy of remark, that, although the severe storms which have repeatedly occurred on the exposed coasts where they are situated,

have done some injury to portions of the stages, and of the temporary works at Holyhead, not a stone would appear to have been carried away from the jetties at either place, and none of the pile standards of the stages at Portland, where they are secured into the ground by Mitchell's screw-pile shoes, have been moved. The success of the system may therefore be said to be complete, in spite of the sinister predictions which prevailed before it was tried.

Mr. Rendel also designed, about the year 1850, and up to his death superintended the construction of, the new harbour at St. Peter Port, Guernsey, and, had he lived, would have constructed the new Harbour of Refuge at Hartlepool, for which an Act was obtained in the year 1855. There is, indeed, scarcely a harbour in the kingdom on which he has not reported, either to the public, or private bodies having their direction. Of those not otherwise noted, mention may be particularly made of the harbours of Ardglass, Chichester, Langston, Lowestoft, Montrose, Peil, Scrimmerston, Wells, and Wexford; and of Port Carlisle. Again in 1844, he made a design for a harbour at Margate; in 1845, his plan for the Dover Asylum Harbour was the one selected by the Royal Commission, although it was not ultimately adopted; in 1848, he designed improvements in the Devonport Dockyard, which have since been carried out by the officers of the Admiralty Works Department; in 1852, he proposed the extension of Wick Harbour, and gave designs for a steam-ship harbour and dock in the river Avon, at Kings Road (Bristol); in 1853-4, he designed the extension of the port of Whitehaven, and a floating dock and other works at Maryport; and in 1854, he reported on Kingstown Harbour of Refuge, with a view of affording increased steam-packet accommodation, and also on a project for a harbour of refuge and commercial basin, at Table Bay, Cape of Good Hope.

He was also much engaged in the improvement of rivers, and especially reported on the rivers Thames, Severn, Tay, Tyne, Lea, Ouse and Nene, the works for the latter of which, extending from Northampton to Wisbeach, with a view both to navigation and drainage, are now in course of construction. He was likewise consulted as to the Norwich and Yarmouth navigation, and the Wye drainage and navigation. In 1846, he designed docks and river improvements for the port of Lynn, portions of which have been executed. In 1852, in conjunction with Sir William Cubitt, M. Inst. C.E., and Mr. Griffith, M. Inst. C.E., he examined and reported to the Treasury upon the Arterial Drainage Works in Ireland. And in 1853-6, he directed the surveys of the river Kowie, Cape of Good Hope, and reported on measures for its improvement.

In 1854, he reported upon a project for a suspension bridge across the Hooghly, at Calcutta; and in 1855, he completed the new sus-

pension bridge across the Ness at Inverness, for the Commissioners of Highland Roads and Bridges.

The fame of Mr. Rendel as a Hydraulic Engineer, naturally attracted the attention of foreign countries, and he was employed by the Sardinian, the Brazilian, and the Prussian Governments, and the Senate of Hamburgh. In 1852-3, he designed docks and other works in the port of Genoa, and in 1854, he was authorized to proceed with the detailed drawings; and the execution of his plan only awaited the return of a more favourable monetary period. He likewise designed a Naval Arsenal in the gulf of Spezia. In 1853-5, he reported on the proposed harbour works at Rio de Janeiro, now constructing under the direction of his former pupil, Mr. C. Neate, Assoc. Inst. C.E.; and also on the plan for the sewerage of the city of St. Sebastian. In 1854, he reported to the Prussian Government on a proposed naval establishment at Heppens, on the river Jade. In 1854-5, he inspected the river Elbe, on the part of the Hamburgh Senate, from Hamburgh to Cuxhaven, and designed various improvements in it, with a harbour at the latter place. These works have recently obtained the sanction of the Hamburgh Senate. He also devised a system of railways for the country between Madrid and Oviedo, as well as improvements of the river Ebro.

He was less engaged in railways than in hydraulic works, but, in England, he executed the Birkenhead, Lancashire, and Cheshire Junction Line, and, in India, he had the direction of the 'East Indian,' and the 'Madras Railways,' the former projected by Mr. (now Sir) Macdonald Stephenson, Assoc. Inst. C.E., as the first of the vast system now being formed, and which will work such a revolution in the destiny of the Indian Empire. The Ceylon and the Pernambuco lines were also under his charge.

He was likewise consulting Engineer for the Regent's Canal and Dock Company, the Lynn Harbour Commissioners, the Exchequer Loan Commissioners, and the Jarrow Dock Company on the river Tyne.

In the year 1856, a report by Mr. Rendel and Mr. Simpson, M. Inst. C.E., on the New Westminster Bridge, caused considerable excitement, and induced much public discussion, relative to that structure; and his designs for the suspension bridge across the ornamental water in St. James' Park, were only completed just before his fatal illness commenced.

About a month previous to his death, he was attacked with what appeared to be simply ague, or intermittent fever; but was, in reality, a fever consequent on internal disease produced by the depressed state of the whole system, due to an overwrought body and mind. For some time he partially rallied, but after much suffering, it became apparent, that his strength was exhausted, and

on Friday morning the 21st of November 1856, he calmly drew his last breath, in the fifty-seventh year of his age.

Mr. Rendel was a man of great energy, clear perception, and correct judgment. He was systematic in his habits, accurate in his observations, ever anxious to discharge his duties to the best of his ability,—generous in disposition, and possessing a warm appreciation for whatever was beautiful, or excellent, in Nature. With an admirable presence, he combined tact and statesmanlike qualities, which very greatly contributed to his success as a man of business. His practical knowledge was well directed, and he knew how to make good use of the scientific acquirements and skill of all whose services he engaged. His evidence before Committees of the Houses of Parliament, was clear and convincing,—seldom failing in carrying his point,—and his reports on engineering works are so well conceived and drawn up, that it may be hoped they will be collected and published for the benefit of the profession. He was very frequently called upon by the Government to report on large works, the most implicit confidence being reposed in his truthfulness, the correctness of his views, and the fearless expression of his opinions. With these qualities, which were fully appreciated, it need scarcely be mentioned, that he rose rapidly to a very high position in the world, as in his profession. He became a Fellow of the Royal Society, and was elected upon the Council; he was a very early Member of the Institution of Civil Engineers, having joined it in 1824, and had been for the last sixteen years upon the Council, holding the post of President during the years 1852 and 1853.

He was as amiable and kind in private life as he was energetic and firm in public, and his decease cast a gloom over the whole of the profession, of which he was a brilliant ornament.

Mr. THOMAS HENRY STATHAM was born at Liverpool, about the year 1810. His father had been for many years Town-Clerk of that extensive borough, and when he resigned that situation, in consequence of the passing of the Bill for the Reform of Municipal Corporations, his retirement was greatly regretted, and created much discussion among the politicians of that town. Young Statham was articled to the late Mr. F. Giles, and during his pupilage, he was intrusted with some extensive marine and other surveys, as well as with the superintendence of the execution of some Dock and Canal works. His first intention was to practise on his own account, and he commenced business in Liverpool, but he was induced to relinquish this, in 1834, when he received the appointment of Resident Engineer on the district

between Basford and Stafford, of the Liverpool and Birmingham Railway, or, as it was then called, the Grand Junction Railway. Here he evinced considerable knowledge of his business, in carrying heavy embankments successfully over large culverts, or arches; and under Mr. Locke, M.P., V.P., he remained on that line until its completion. In the course of the construction of these works, Mr. Statham met with an accident on the Madeley Incline, from incautiously jumping off a locomotive engine when descending the incline at full speed, one of the wheels passing over his foot and rendering him a cripple for life. The Grand Junction Line was completed, in July, 1837, and whilst still suffering from the effects of this accident, Mr. Statham, through the recommendation of Mr. Locke, received the appointment, in 1838, of Resident Engineer of the Southern, or Brighton extremity of the London and Brighton Railway, which also included a branch to Shoreham. The works on this portion of the line were very heavy, and he carried them out with such ability, that after the completion of this line, in 1841, he was appointed Managing Engineer both of the works and of the rolling stock, including the locomotives of the whole of the line. This post he held until June 1845, and conducted it with great satisfaction to the Directors, but on a change of management, he sent in his resignation.

In the years 1847 and 1848, he was engaged in surveying and setting out lines of railway in the West Indies, upon which he wrote some able reports, accompanied by estimates, &c. During the last few years of his life, Mr. Statham was intrusted by Mr. Hawksley, M. Inst. C.E. with the superintendence of the construction of a portion of the New Liverpool Water-works.

Mr. Statham was a man of good natural abilities, and great energy of character; he was an excellent surveyor, with much experience in the practical parts of the profession, taking considerable pride in the excellent finish of the works under his charge. He had an agreeable manner, and was much respected by the mechanics and others employed under him. He was elected a Member of the Institution in 1845, but could only seldom attend the meetings. His death occurred on the 15th of October 1856, in the forty-sixth year of his age.

Mr. FRANCIS WHISHAW, third son of the late Mr. John Whishaw, solicitor, was born on the 13th of July, 1804. He received a sound education, and having displayed, whilst at school, peculiar aptitude for the mathematical and mechanical sciences, it was determined that he should adopt the profession of an Engineer. He was accordingly articled to Mr. James Walker, M. Inst. C.E.

During his pupilage, he was employed in the year 1824, in preparing plans and sections for a railway to be laid down on the Commercial Road, between London and Blackwall. Subsequently, however, a granite tramway was substituted, extending from the entrance of the West India Docks to the top of the Commercial Road. At this time he constructed a model of a flat arch springing from cast-iron plates, connected by wrought-iron ties, so as to counteract the outward thrust, and to facilitate the building of arches with a small rise, and to reduce the thickness of the superstructure. This system has since been extensively adopted in the construction of fire-proof floors.

In 1832, perhaps from living in the neighbourhood, he first directed his attention to devising means for avoiding the evils and dangers of Holborn-hill, which were constantly apparent to him. For this purpose he made a careful survey of the whole district, ascertaining that the average gradient of Holborn-hill was 1 in 24, the greatest inclination being 1 in 14½, and the least 1 in 131; whilst Skinner-street was not much better, the average gradient being 1 in 32. He then suggested the construction of a Viaduct, extending from the Newgate-street end of the Old Bailey, passing over Farringdon-street and market, and to the north of New-street Square; thence by a gentle curve across Plough-court, Blewitt's-buildings and Bartletts'-passage, to the point where Fetter-lane falls into Holborn. By this route the distance would only have been increased about 30 yards, whilst the road would have been level from Fetter-lane to Farringdon-street, and have had an inclination of 1 in 73 from the latter street to the Old Bailey, He presented a petition to Parliament in favour of this project, accompanied by detailed estimates and lithographic drawings; and a model of the design was exhibited for some time in the Adelaide Gallery. What Mr. Whishaw said of this district in August 1835,[1] that "while almost every part of London is daily improving, Holborn-hill remains nearly the same as it has been for centuries," is still a lamentable fact. About this time he published a comparative plan of London, showing the alterations from 1666, the year of the Great Fire, to 1829. In 1830, he was instructed to report upon a proposed railway between Perran-porth and Truro, in Cornwall, a distance of about 8 miles, and subsequently, on two other occasions, he was consulted, with Mr. R. Thomas, on the same subject. In 1835, in conjunction with Mr. T. L. Gooch, M. Inst. C.E., he acted as an Assistant Engineer, under Mr. R. Stephenson, M.P., President, and was employed in preparing the estimates for

[1] *Vide* "Holborn Hill Improvements. Report on the projected Viaduct from Fetter Lane to the Old Bailey, and Improvement of Farringdon Market." Tract. 8vo., vol. liv. Plates. London, 1835.

the Manchester and Leeds Railway, and in arranging the requisite proceedings, in Parliament. In 1836, he reported on the proposed Hertfordshire Grand Union Railway, which was to form a junction between the London and Birmingham and the Northern and Eastern Railways, and to give railway communication to the towns of Watford, St. Alban's, Hatfield, Hertford, and Ware. In the year 1837, Mr. Whishaw brought out his "Analysis of (projected) Railways,"[1] at which time, as the Preface sets forth, he had given seventeen years' attention to engineering pursuits, and had made repeated surveys of the principal railways of Great Britain. A second edition of this work was published in the following year, and its success was so great, that, in 1840, Mr. Whishaw dedicated "to the Railway Capitalists of the United Kingdom," a quarto volume entitled "The Railways of Great Britain and Ireland, practically Described and Illustrated."[2] Before this book was written, he took a railway "trip," as he called it, of 7,000 miles, to collect matter for the work, and only three months elapsed, from the time he began to write it, to the day of its publication.

In 1841, he also published a Railway Map, on which he showed upwards of 1,600 miles of new lines, which he thought necessary to complete the railway system, in addition to about 1,700 miles of railway then open. Several of the proposed lines have since been executed.

In the years 1837 to 1840, but principally in 1839, he conducted a series of practical experiments as to the actual working of the trains on all the British railways at that time open, with the view of ascertaining the amount of power employed in ascending and descending different gradients, and the cost of working. The result of this inquiry induced the expression of an opinion, since more generally acted upon, that too much money was expended in obtaining, what were then termed, good gradients. It also led him to advocate the construction of single lines, with passing stations, so that the railway system might be extended into every portion of the United Kingdom. He proposed, that at the passing stations, the locomotive engines should be reversed, so as to be kept at work on that division of the line for which they might be specially adapted. In this year (1839) he presented two Papers to the Institution, one on "A new mode of preparing Railway Sections, as illustrated by that of the Manchester and Leeds

[1] *Vide* "Analysis of Railways; consisting of a Series of Reports on the Twelve Hundred Miles of Projected Railways," &c. By F. Whishaw. 8vo. London, 1837.

[2] *Vide* "The Railways of Great Britain and Ireland, practically Described and Illustrated." By F. Whishaw. 4to. Plates and Diagrams. London, 1840.

Railway,"[1] and the other "Observations on the present mode of executing Railways, with suggestions for a more Economical, yet equally efficient system, of both executing and working them."[2] This latter Paper was subsequently extended, and published in extenso, under the title of the "Reciprocating System of Railways," in the treatise on the "Railways of Great Britain," before referred to. The subject was again brought forward, when Mr. Whishaw occupied the post of Secretary to the Society of Arts, where he read a Paper "On the Means of extending the Railway System into every portion of the United Kingdom,"[3] in which he also described the atmospheric system, then at work on the Dublin and Kingstown Railway. In connection with the railway system, it may be mentioned, that Mr. Whishaw, in a discussion at the Institution, in February, 1845, upon Mr. Vulliamy's Paper "On the Construction and Regulation of Clocks for Railway Stations," laid claim to having suggested, in 1841, that Greenwich mean time should be adopted for ordinary purposes throughout the kingdom; and that all the clocks along the different lines of railway should be regulated to the same time, by means of the electric telegraph.[4]

He had in the previous Session (1838) presented to the Institution a Memoir on the "History and Construction of (Labelye's) Westminster Bridge, accompanied with detailed drawings,"[5] for which a Telford Medal was awarded to him. This Paper was looked upon at the time, as having given a good history of the state of engineering a century back, and as a historical record, displaying great labour and research, which it was most desirable for the Institution to possess. Westminster Bridge was the only old bridge remaining, and the contrivances there first brought into use, particularly the mode of building by caissons, the result of their employment, and the progress since made, were most interesting to engineers.

In 1837, he invented the Hydraulic Telegraph, which attracted great public attention, and was favourably reported on by officers of the Government; but the introduction of the electric telegraph, which occurred at nearly the same time, prevented its being extensively used. The attention he paid to the subject of telegraphy, induced the consideration of arithmography, or the foundation of a code of signals, by means of the varied combination of numerals, which should be universal in its application; each particular arrangement of figures being made to represent the same word, or thing, in all languages. By this system he con-

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1839), p. 43.
[2] Ibid., p. 53.
[3] *Vide* Trans. Soc. Arts, vol. lv., p. 183.
[4] *Vide* Minutes of Proceedings Inst. C.E., vol. iv., p. 71.
[5] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1838), p. 44.

ceived, that greater expedition would be insured, and he commenced the preparation of a general arithmographical lexicon, but did not proceed very far with it. An account of his views on this subject was laid before the Society of Arts in 1843.[1] About this time he also communicated to the same Society, two papers on the electric telegraph; one "On the Application of Electricity to the transmission of Telegraphic Signals,"[2] in which he described the system then in daily use on the Blackwall, Edinburgh and Glasgow, and Manchester and Leeds railways; and the other on "Cooke's improved arrangements of the Conducting Electric Telegraph,"[3] as adopted on the Great Western Railway. In November, 1844, he publicly exhibited at the Society of Arts, the first specimens of Gutta Percha which came to this country. He pointed out, at the time, the applicability of that substance, as bands for driving machinery, in place of the ordinary leather bands, as well as the facilities it afforded for reproducing mouldings, cornices, and copies of works of art. Subsequently, in 1846, he was engaged by the Electric Telegraph Company, under the presidency of Mr. J. L. Ricardo, M.P., to form the Signal-Clerk department, but he left the Company before any very material progress was made. His system of signals, is, however, with some modifications, still in use throughout the kingdom. Upon the conclusion of his engagement Mr. Whishaw was presented with a piece of plate by the officers of the Electric Telegraph Company who had served under him. He devoted much time to the question of the introduction of the electric telegraph into India; and with this view examined the telegraphic establishments of England, France, and Prussia. During the Chairmanship of Mr. Shepherd, he, in conjunction with Mr. Hyde Clarke, laid before the Honourable East India Company, a report which tended to determine the adoption of the system for India, though the organization was intrusted to other hands. In this report he recommended that the underground system of laying the line-wires, as carried out in Prussia, should be adopted in that territory, instead of the suspended, or overground system, almost universal in England. The theoretical correctness of this opinion was to some extent confirmed by the experiments of Dr. (now Sir W. Brooke) O'Shaughnessy, to whom was confided the execution of the Indian telegraphs, a work which he has brought to a most successful issue, but from local circumstances the suspended system has been adopted.

About this time he was appointed the Consulting Engineer to the Gutta Percha Company, and he suggested many valuable

[1] *Vide* Trans. of Soc. Arts, vol. liv., p. 176.
[2] Ibid., p. 170. [3] Ibid., p. 172.

applications of that material, particularly endeavouring to render it useful for telegraphic purposes. But perhaps the greatest of Mr. Whishaw's public services was the direction of his energies to the resuscitation of the Society of Arts, which would probably have died a natural death, had he not opportunely assembled a few influential men who afforded him their support as Secretary, in his highly meritorious and successful task, for the accomplishment of which he is fairly entitled to great praise. About the end of the year 1842, it was seriously contemplated to break up the Society, and a resolution was passed, though never acted upon, to the effect that the funds were no longer sufficient to retain the services of a salaried Secretary. It was under these circumstances that Mr. Whishaw entered upon the duties of that office. He was very energetic and successful in personally canvassing for members, inducing one hundred and forty new members to join within a few months; and he at once introduced improvements in the character of the evening meetings, by obtaining and contributing Papers for discussion. These efforts, combined with the alterations in the general principles and management of the Society, introduced by other Members, who began to take an interest in it, may be said to have laid the foundation of its present prosperity. The communications he laid before the Society, which have not been previously noticed, were, in 1843, "On the Great Pyramid of Gizeh,"[1] from information supplied by Mr. J. K. Perring; and on "Messrs. Young and Delcambre's Type-setting Machine,"[2] in which the letters were arranged in tubes, or columns, all of the same length, and so placed, that by touching keys, somewhat similar to those of a pianoforte, any particular letter could be released, and thus any desired word, or combination of words, could be composed. In the following year he contributed papers, "On Means of preserving Life in cases of Shipwreck,"[3] to which subject the Society had, for upwards of fifty years, paid marked attention, had accumulated many facts regarding it, and had rewarded numerous inventions designed to facilitate this laudable object. Also "On the Means of Cleansing daily the Streets of the Metropolis,"[4] which Mr. Whishaw, as early as the year 1821, had proposed to carry out by the partial employment of the poor; on "Robson's Patent Signal Lights;"[5] on "Rendering Paper Hangings useful as well as ornamental,"[6] in which he described the three processes then practised in printing paper hangings, and suggested that the papers for the walls of schoolrooms and lecture halls, should be arranged in

[1] *Vide* Trans. Soc. of Arts, vol. liv., p. 187.
[2] Ibid., p. 168.
[3] Ibid., vol. lv., p. 59.
[4] Ibid., p. 113.
[5] Ibid., p. 134.
[6] Ibid., p. 150.

panels, and that these should be filled in with such things as it might be desirable to implant firmly in the minds of the pupils; "On the Management of Bees;"[1] and on the "Manufacture of Casks, more particularly those used by brewers, with remarks on the various methods adopted for cleansing and purifying such vessels." Subsequently, in 1847, he read a Paper "On the Application of Heated Currents to Manufacturing and other Purposes,"[2] in which he described Messrs. Davison and Symington's process for seasoning wood, preserving timber, purifying animal productions, and drying manufactured articles, &c.

In 1844, Mr. Whishaw gave the first *soirée* held at the house of the Society of Arts, which led to a series of *conversazioni*, that soon became the acknowledged *réunions* of all the leading professors of science and art. In the autumn of that year, he attempted to get up an exhibition of paintings, at which money prizes were to be awarded, the candidates themselves to be the judges. The advantages of exhibitions had long been known to the Society, the different forms best suited to advance the Society had often been the subject of discussion, in which Mr. Whishaw, as an active member, took a leading part, and it is probable that he, and all who were in favour of exhibitions and had visited the Paris 'Expositions,' had vague notions of the benefit to be derived from some Great Exhibition. But the particular exhibition recommended by Mr. Whishaw was limited to the products of British industry, as shown by his own advertisement inserted in the "Athenæum" at the time, in which prizes were offered to the amount of £300 for a design for a suitable building, and for paintings, inventions, &c. A private subscription was afterwards raised, and Mr. Whishaw, at the request of some of the influential members of the Society of Arts, visited the chief manufacturing districts as its agent, with the view of ascertaining the feelings of the manufacturers. In the summer of 1845, he accepted an appointment in connection with Prosser's wooden railway, relinquishing the post of Secretary to the Society of Arts, in which he was succeeded by Mr. J. Scott Russell, M. Inst. C.E. When he withdrew from the active duties of Secretary, the Society was in a much improved condition, and his name was retained, in conjunction with Mr. Russell's, for two years. On retiring in 1847, he was elected an Honorary Member of the Society. With regard to the Exhibition question, it may be mentioned, that although, at this period, no direct movement was taken, beyond the small annual Exhibitions of Manufactures held in the Society's rooms, the first of which took place in 1847, yet the subject was kept alive as opportunity offered; friends were conciliated, and

[1] *Vide* Trans. Soc. of Arts, vol. lv., p. 160.
[2] Ibid., New Series, p. 145.

opposition was neutralized. Mr. Whishaw, having abandoned his idea of a National Exhibition, co-operated with the Council of the Society, in June, 1849, in endeavouring to find parties willing to advance the necessary funds for carrying out a Universal Exhibition; and at last sufficient progress was made to justify an appeal to the public. Of these preliminary proceedings the Great Exhibition of 1851 was the result, the peculiar feature of its universality and of its international character, being due to Mr. Thomas Winkworth, long an active Member, and now a Vice-President, of the Society. The General Executive Committee appointed to arrange the preliminary proceedings for the proposed international Exhibition consisted of Messrs. H. Cole, F. Fuller, J. Farey, J. Woods, and G. Munday (the proposed Contractor for the building), with Mr. J. Scott Russell (the Secretary), and Messrs. J. Payne, P. Le Neve Foster, and T. Winkworth (Treasurers), and by them the patronage of His Royal Highness the Prince Albert, as President of the Society of Arts, was sought and obtained. The matter was then taken up by Sir Robert Peel, Lord Granville, and others, and was brought to a successful issue. In connection with the Exhibition, Mr. Whishaw was engaged to visit the manufacturing districts, and he wrote a series of articles on the mechanical department, which appeared in the "Illustrated London News."

During the latter years of Mr. Whishaw's life, he was a great sufferer from bodily illness, and was, in consequence, unable to attend to professional duties, or to those questions which had so long occupied him. To a man of such indefatigable perseverance this was a source of much sorrow, for in the business of life he displayed such zeal and earnestness, that he could not rest till all that he undertook was accomplished. His earthly career was suddenly terminated, on the 6th of October 1856, in the fifty-second year of his age. Mr. Whishaw joined the Institution of Civil Engineers as a Member in the year 1834, and as will have been gathered from the preceding summary of his life, took an active personal interest in its welfare, by contributing papers and taking part in the discussions.

MR. THOMAS JACKSON WOODHOUSE was born at Bedworth, in the county of Warwick, on the 9th of December, 1793. He was the son of Mr. John Woodhouse, Civil Engineer, whose Father also had followed the same profession. He was educated under Mr. Thomas White, the head master of a school, of King Edward's foundation, at Towcester, in Northamptonshire, which during the early part of this century, enjoyed a high reputation,

and from whence emerged several scholars who, in after life, became eminently successful in their various avocations. In 1809, when the time arrived for him to select a profession, he evinced the same spirit which actuated so many youths at that period, when a desolating war was being carried on by land and by sea,—he desired to become a sailor,—and although his wishes were for a long time combated by his parents, they at last reluctantly complied with his ardent desire. An appointment was procured for him, as Midshipman on board the 'Broxonbury,' one of the Honourable East India Company's ships. This was before the trade with the East Indies had been thrown open, and when the Honourable East India Company's vessels were armed, and the crews disciplined like men-of-war.

On his return from his first voyage to Calcutta, he yielded to the urgent remonstrances of his parents, and embraced the profession of a Civil Engineer, the rudiments of which he learned under his Father, who was at that time Engineer for many important works. He was first engaged on the Grand Junction Canal, including the Blisworth Tunnel, where great difficulties had to be overcome, in consequence of the large quantity of water which had to be contended with. This is still, perhaps, the longest tunnel, for canal purposes, in existence. He was then employed upon the works of the Worcester and Birmingham Canal, including Tardebig Tunnel, and a large number of locks. His next work was upon the Gloucester and Berkeley Ship Canal, which required extensive sea-walls, and a pier at Sharpness Point, the entrance from the Severn, where the tide flows with extraordinary force and velocity.

In 1825, in connexion with the late Mr. Josias Jessop, he surveyed a line for a railway from Birmingham to Bristol, which was not executed, in consequence of the mercantile panic at that period.

In 1826, he was appointed resident Engineer to the Cromford and High Peak Railway. This line passes through a wild mountainous country, rising 1,000 feet from the Cromford Canal, and falling 800 feet to the Peak Forest Canal, at Whaley Bridge. There is a tunnel on the summit about half a mile long. The Act for this line was passed in the same session as that for the Liverpool and Manchester Railway, and they were both made during the same period. In consequence of the hilly nature of the country, the gradients were necessarily steep, so that it was deemed advisable to work the line by means of stationary engines, and with horses.

In 1832, he was appointed Engineer of the Dublin and Kingstown Railway, which, being chiefly situated on the sea-shore, exposed to heavy easterly gales, was attended with much difficulty in

the construction, but it has stood the test of many violent tempests. In overcoming the difficulties which arose here, he displayed great talent, as well as zeal and assiduity.

In 1834, when surveyors were first appointed for the counties in Ireland, the Board of Public Works threw all the appointments open to competitive examination. Mr. Woodhouse was one of the candidates, and his name being placed first on the list, he was allowed to select the county he desired to be attached to; when he fixed upon Antrim, as the most important, because it included Belfast. He was afterwards appointed Engineer for the Belfast Harbour trust, and also for the railway from Belfast to Lisburn; but when the latter was finished, seeing no probability of railway works proceeding in Ireland for some time, he, in 1836, accepted the appointment of Resident Engineer to the Midland Counties Railway, for connecting Derby, Nottingham, Leicester, and Rugby. In the execution of sixty miles of railway, through so hilly a country, in those, comparatively, early days of railways, difficulties and obstructions necessarily presented themselves; but these were all successfully overcome, by the untiring energy and perseverance, coupled with ability, displayed by Mr. Woodhouse, and he was particularly careful to husband the resources of the Company, and to introduce no unnecessary, or ornamental work. Among the many works on this line may be particularly instanced the bridge over the river Trent, a light structure of iron, consisting of three arches, each of 100 feet span, and of 10 feet rise. It was thought by some Engineers that this bridge did not possess the requisite strength; but subsequent experience has shown it to be fully equal to support the heavy traffic passing over it. In the execution of these works, he won the regard and esteem of all with whom he was engaged. The Resident Engineers appreciated his unvarying kindness, and solicitude for their welfare; the Contractors admired his honest and upright conduct, and desire to comply with all fair and equitable demands; and the Directors knew that they had a worthy and faithful servant, who, on all occasions, endeavoured to act as an impartial arbitrator between the Company and the Contractors. In this he was so successful, that in the expenditure of one million sterling, for work and material, not a single case of litigation arose. In recognition of the services performed on this occasion, a subscription was entered into, which soon reached one thousand guineas. With this it was determined to purchase a handsome dinner service of silver, bearing the following inscription:—

"Presented to THOMAS JACKSON WOODHOUSE, Esq., Civil Engineer, by the Resident Engineers, Contractors, Manufacturers, and other gentlemen connected with the construction of the Midland Counties Railway, as a token of their estimation of his talent, zeal

and integrity, manifested on all occasions in carrying out the above important undertaking, May 27, 1841." The presentation took place at a public dinner, at Derby, when about seventy gentlemen, connected with the railway, and with the town and neighbourhood, attended and expressed their public estimation and their private friendship for him.

When Mr. Woodhouse's engagement as the Resident Engineer of this company terminated, the Board of Directors passed the following resolutions:—"1. That this Committee entertain the highest sense of the faithful, zealous, and truly able and efficient manner in which Mr. Woodhouse has discharged the various duties of his office, and the unremitting assiduity he has evinced, in promoting the interests of the Company, during the whole period of his engagement. And that the warmest thanks of this Company be presented to Mr. Woodhouse for his constant exertions, and for the eminent service he has rendered to them on all occasions. 2. That Mr. Woodhouse be requested to accept a perpetual free ticket for passage over the railway, in acknowledgment of the advantage its interests have derived from his services."

In 1842, he surveyed the line from Leamington to Coventry; but when the Act was obtained, the line was transferred to, and was executed by, the London and North Western Company.

He then went to France, for Messrs. Brassey and Mackenzie, to construct a canal for uniting the rivers Rhone and Marne. In 1843, he was appointed Engineer-in-chief for the railway from Orleans, Tours and Bordeaux, and remained there until the Revolution of 1848, when he returned to England. He was, however, so generally popular, from his mild and conciliatory manners, that during the period of the wild excesses to which the Revolution led, with the peasantry excited against Englishmen, he was not in any way molested, or interfered with. But as he would have had to carry on the works with a, comparatively, inexperienced staff, all natives of France, he thought he should best consult his own interest by resigning. Shortly afterwards, he was engaged by Mr. Brassey to go to Italy, to make a line of railway from Prato to Pistoja. When that line was completed, he undertook for the same gentleman, the construction of the railway from Turin to Novara, and he had finished about sixty miles of it, when he was seized with illness, which eventually proved fatal. He was in the full enjoyment of good health, until about the middle of September, 1855, when, after considerable exertion in examining the country, in the neighbourhood of Milan, with the view of an extension of the railway from that city, he received a 'coup de soleil,' from the effects of which he expired, at Turin, on the 26th of September, in the sixty-second year of his age. He had so completely gained the respect and esteem of a large body of the citizens, that his remains

were followed to the cemetery, by a greater number of persons than had, on any former occasion ever paid the last mark of respect to a Protestant in that city. The Piedmontese journals, at the same time, published highly eulogistic articles respecting his character as a man, and his abilities as an Engineer.

Mr. Woodhouse became a Member of the Institution in the year 1838. Those who knew him best, considered him to be an excellent judge of work, and of its fair value to a Contractor, and they placed great reliance on the accuracy of his estimates; and his unassuming and conciliatory demeanour was of great value in many difficult negotiations and arbitrations. His constant avocations at a distance from the Metropolis, prevented his taking any active part in the affairs of the Institution, but he always evinced great interest in its welfare.

Mr. JAMES BEATTY, son of Dr. Beatty, was born on the 31st March 1820, at Enniskillen, in Ireland. He was educated in classics by his Father, and in English and mathematics by masters. He so early in life showed such mathematical and constructive talent, that his Father determined upon the profession of a Civil Engineer for him. Accordingly, when about fifteen years of age, he became a pupil of the late Mr. T. J. Woodhouse, M. Inst. C.E., who was at that time engaged, as Resident Engineer, in the construction of the Midland Counties Railway. This gentleman had a high opinion of young Beatty, who became so useful, that at the expiration of his pupilage, he was employed for two years as an Assistant Engineer on the railway. In 1840, he was engaged in surveying the Manchester and Derby line.

In 1842, he was engaged by Messrs. Peto and Betts on the Norwich and Brandon and Lowestoft lines; and in 1845 he was appointed by the same firm their chief Agent and Engineer, charged with the execution of the works on the Southampton and Dorchester Railway. In the summer of 1852, he was sent out by Messrs. Peto and Betts, with Mr. Donald Campbell, appointed by Mr. J. Locke, M.P., V.P., to explore and lay out the European and North American Railway, in New Brunswick, a link in the chain of railways, intended to connect Halifax, the nearest port to England, with the inmost recesses of Canada and the United States. On arriving at St. John's, there remained only about three months, in which to make the necessary surveys, sections, &c., the greater portion being through the primæval forest. However, owing to Mr. Beatty's great energy, and by incredible exertions, trial sections were taken in every direction; from St. John's to Shediac, on the Gulf of St. Lawrence, on the east, and to St. Andrew's and the frontier of the United States, by two different

routes, on the west; and from Shediac to Miramichi, northwards. The permanent surveys, and estimates of the works, were also so far advanced, as to enable the contract for the portion from St. John's to Shediac to be made between the New Brunswick government and Messrs. Peto and Betts. Mr. Beatty then returned to England, late in the autumn, and, in the following spring, he was appointed Engineer-in-chief of the New Brunswick Railways. But on the eve of sailing, his destination was suddenly altered to Nova Scotia, where he proceeded, to explore and lay out the portion, in that province, of the great system of railways; Mr. Giles being subsequently sent to carry out the works in New Brunswick.

In Nova Scotia, as in New Brunswick, the surveys had to be made through the dense primæval forest. Through this, the different surveying parties at once proceeded literally to cut their way; often felling, within twenty, or thirty yards, half-a-dozen splendid trees, invaluable in a park in England, but sadly impeding the progress of the surveys, where they were. By Christmas, however, trial sections had been taken all over the country, the line was surveyed, and permanently staked out, over the whole extent, from Halifax to Truro, and from thence by two routes, one round and the other across the Cobequid Mountains, to the New Brunswick frontier, as well as branches from Halifax to Windsor, the direct line to St. John's, New Brunswick, and from Truro to Pictou, the route towards Prince Edward Island. During the whole of this period the various parties had been "camping out," living in the woods with a thin canvas single tent for a covering, salt pork and hard biscuit for provisions, and for the last month three feet of snow on the ground, with the thermometer down to 15° below zero. Mr. Beatty was continually moving from party to party, encouraging and stimulating all to the greatest exertion by his own example, and taking his share of the hardships of the situation.

The war with Russia broke out, at that period, and capitalists hesitated on entering into large engagements, in the then unsettled state of affairs. Accordingly, in February 1854, Mr. Beatty and his staff finally left the shores of America, carrying with him the good wishes and hearty esteem of all with whom he had come in contact.

The war, meanwhile, went on, and the allied armies were reduced to very severe straits in the winter of 1854, one of the principal difficulties, if not the greatest, being the want of land transport. It was then suggested to the Duke of Newcastle by Mr. (now Sir Morton) Peto, Assoc. Inst. C.E., to construct a railway from Balaklava to the front, which, although the ground was not favourable for an ordinary railway, would, it was presumed, be of great service in facilitating the transport of stores and ammunition. The Government having adopted the suggestion, intrusted

the whole of the arrangements to Messrs. Peto and Betts, who appointed Mr. Beatty Engineer-in-chief. After remaining a short time in England, to organize the Railway Corps, and make the necessary arrangements, he proceeded by the overland route to the Crimea, where he arrived on the 19th January 1855. Having approved of the line which had been surveyed and laid out by Mr. Donald Campbell, the Assistant Engineer, who had preceded him about four weeks, he at once applied to Lord Raglan, for such military assistance as could be spared, in order to prepare for the arrival of the navvies and the railway material. A party, varying from one hundred and fifty to two hundred men, from different regiments, was daily allotted to this duty, and was employed in converting a vacant space of ground in Balaklava, which had hitherto been in a shocking state of disorder, and filth, into a good yard, using for that purpose the debris of some ruinous old houses, and in making a solid foundation for the sleepers along the soft and muddy valley of Balaklava, with stones taken from the neighbouring walls. This assistance was continued for about ten days, until the arrival of the navvies, when the men were divided into shifts, and worked day and night, until the village of Kadikoi was reached. This was effected in about ten days from the landing of the first rails. Shot and shell were then conveyed to that distance on the railway, saving the fatigue parties who had to carry them on their backs to the front, either slung in canvas bags, or between a couple of short poles, three miles of their muddy tramp, and freeing the already overcrowded harbour of Balaklava from the presence of that number of men.

In the mean time the works were being pushed on vigorously towards the plateau; two hundred sailors were lent from the Naval Brigade for ten days, who evinced in their novel employment, the same hearty spirit and good-humoured activity which characterized all their operations, however foreign to their usual habits. In about seven weeks the Col was reached, a distance from the commencement of the railway of about four miles and a half, and at an elevation of 660 feet above the level of the sea; a branch of three-quarters of a mile to the Ordnance, or Diamond Wharf, laid; the stationary engines at Frenchman's Hill fixed and at work; and the line from Balaklava to Kadikoi made double. Stores were conveyed along the railway, simultaneously with the prosecution of the works. The remainder of the distance to the camps was comparatively level, and from the traffic being spread over a large surface, the ground was not so much cut up. The line was further extended to the Woronzoff road, between the Second and Light Divisions, with a branch winding round the rear of Cathcart's Hill, to a spot between the Third and Fourth Divisions. A branch, about three miles in length, was afterwards made from Kadikoi

towards the Sardinian camp, over the scene of the Heavy Cavalry charge, and General Della Marmora, before leaving the Crimea, expressed his sense of the service it had rendered to his corps.

During all this time whatever masons, carpenters, or others of the Railway Corps could be spared, from the more immediate railway works, were employed in building limekilns, bakeries, wharves, and huts, and in sinking wells, &c. A considerable number of the men were employed on the line as brakesmen, until the men of the Land Transport Corps, who afterwards worked the traffic, had obtained the requisite experience. By the beginning of August the term of service of the navvies had expired, and on their being sent home, Mr. Beatty was invited by Lord Panmure to remain in charge of the railway, and Mr. D. Campbell was confirmed in the post of Assistant Engineer. Pending the arrangement of a new railway department, a number of men were ordered to be detailed for service on the railway, according to Mr. Beatty's requisition, from the Army Works Corps, which had been organized and sent out from England by Sir Joseph Paxton, Assoc. Inst. C.E., under the charge of Mr. W. T. Doyne, M. Inst. C.E., as Superintendent-General. The traffic department being now entirely carried on by the Land Transport Corps, the men lent from the Army Works Corps were employed in ballasting the line, in anticipation of the coming winter, the embankments were raised, and the cuttings lowered, in order to improve the line as much as possible, the great desideratum at first having been to get it opened with the least possible delay.

Mr. Beatty's health, which had been very much affected by an accident, at last gave way, and after proceeding to Scutari for a short time, by medical advice, he was, as a last chance, finally invalided to England, for which place he left in November 1855, to the great regret of all who knew him. The proximate cause of the failure of his health was the accident previously alluded to. The 71st Regiment, quartered near Balaklava, was ordered up to work in the trenches on one occasion, and the men were conveyed to the front on mules. Lord Raglan wishing them to return by railway, the regiment was divided off into three trains, two of which went down the incline, from the Col to the stationary engine, averaging 1 in 25, in safety; but the last train, in which were Mr. Beatty and the Officers, owing to the dew on the rails, and the rapidly-increasing darkness, got too much way on it, overpowered the breaks, and went down at a fearful speed. In endeavouring to stop it Mr. Beatty was thrown out, and received internal injuries from which he never recovered.

He reached home in December 1855, and lingered in great suffering until his death, which occurred on the morning of the 11th March 1856. During this period he still retained the

liveliest interest in everything connected with the railway in the Crimea, receiving reports from his assistants, and directing them at a distance with his advice. His complaint, however, baffled the physician's skill. There was the same robust and vigorous frame, and no outward appearance of disease, until a fortnight previous to his death. Then a swelling of the throat and the left arm commenced, accompanied by difficulty of breathing, and a painful sensation of suffocation when reclining, which confirmed the belief, that the accident in the Crimea had produced aneurism. On the announcement of his impending fate being made to Mr. Beatty, he received it with Christian fortitude and resignation, and, with that energy which was his chief characteristic, proceeded to arrange his affairs.

He exhibited great energy and application in the pursuit of his profession, which seemed only to augment as difficulties presented themselves. Whenever and wherever work was to be done, he always led, and took the largest and the hardest share. His presence seemed to inspire confidence, and his constant cheerfulness acted as a powerful incentive and stimulus to those around. Frank, openhearted, and amiable in his communication with his fellowmen; upright and just in all his dealings; liberal and generous, no wonder that he was universally beloved.

He joined the Institution as an Associate in 1852, but his constant occupation abroad after that date, prevented any frequent attendance at the meetings. His early death has been a source of great regret to those who knew him best, as they had predicted for him a brilliant career.

MR. THOMAS CUBITT was born at Buxton, near Norwich, on the 25th February, 1788. In early life he worked as a journeyman carpenter, and with a view to improve his circumstances, he made one voyage to India, as a ship-carpenter. With the savings he then made, he, on his return to London, commenced business as a master-carpenter, being at the time about twenty-one years of age. His first work, of any extent, was putting the new roof on the Russell Institution, in Great Coram-street, under the superintendence of Mr. John Shaw, then architect to Christ's Hospital, London. This was completed to the entire satisfaction of the committee and of the architect, so that when tenders were advertised for, for the building of the London Institution, in Finsbury Circus, Mr. Cubitt's offer was accepted, mainly on the recommendation of those who knew how well his work had been done at the Russell Institution. The foundations were laid in May, 1815; and, shortly afterwards, as appearances of success began to manifest themselves, he took a tract of land from Lord Calthorpe, on the east side of Gray's Inn-

road. Here he commenced the erection of large workshops, purchased horses, carts, and materials, and engaged gangs of carpenters, smiths, plumbers, glaziers, painters, bricklayers, &c., with a foreman for each class. Before that time, the building trade had not become, as now, a regular business, but was divided among different branches, which, in a manner, worked independently of each other. Finding the inconvenience of this, he employed workmen of all these classes, and consolidated them into one establishment. As this increased, he found, at times, a difficulty in obtaining a constant succession of work, so as to keep his men regularly employed, without the necessity of discharging them, just as they had become used to his system. This first led him to take ground to build upon, a species of speculation which afterwards became the employment of his life; for as these engagements became greater, they gradually absorbed his capital and attention, until he finally relinquished the general business at Gray's Inn Road to his Brother, William (the present Mr. Alderman Cubitt, M.P. Assoc. Inst. C.E.), and, with very few exceptions, entirely devoted himself to building, from his own designs and on his own ground. His plan was to take a large tract of unoccupied land, sometimes from several distinct land-owners, and to lay it out on one great plan of squares, streets, roads, &c., as a whole, sparing no expense in the outset, in drainage, forming gardens, planting, laying out wide streets, and using every endeavour to keep up the character of the whole.

His first undertaking of this kind was at Highbury, occupying a commanding site in the parish of Islington. Here he erected some moderately-sized villas, with good gardens, which were soon eligibly let and sold. He next raised detached villas and rows of houses on a piece of land between Newington-green and the principal street of the parish, and, in this instance, he had to make roads of approach to the proposed new buildings. He then purchased, and made freehold, a nursery-garden and grazing-ground, six acres in extent, called Barnsbury-park, abutting on the Liverpool, or North-road. This land he laid out for streets and squares, and built a few houses and villas as examples, letting off the remainder to other builders, who erected houses on a smaller scale.

About the year 1824, a large tract of land in the parish of St. Pancras, within a short distance of the establishment in Gray's Inn Road, attracted his attention. Having taken a lease for ninety-nine years from the Duke of Bedford and Lord Southampton, the ground landlords, he successively built the houses of Upper Woburn-place, Woburn-buildings, Gordon-square, Tavistock, Gordon, and Endsleigh-streets, as also nearly the whole of Gordon-square, with part of the south side of Euston-square. Perceiving the tendency of the fashionable world to move westwards, Mr. Cubitt, in the

latter end of 1824, or early in 1825, fixed upon a tract of land, upwards of 140 acres in extent, belonging to the late Marquis of Westminster and Mr. Lowndes, near to Buckingham Palace, and known as the Five Fields, Chelsea, with the ground adjacent. On this locality, Belgrave-square, Lowndes-square, Chesham-place, and other ranges of houses, were erected. In 1829, Mr. Britton wrote the following remarks on this district, for 'The Picture of London,' then reprinting:—"Within five years, this land has been nearly covered with houses of the largest size, surrounding spacious squares, or on the sides of wide and handsome streets. Of all the extraordinary building-works carried into effect by a London gentleman or tradesman, we may fairly adduce this as unparalleled. Most of the houses surrounding one large square, (Belgrave,) have been erected, some of which are finished and occupied, and several others of equal dimensions and value are nearly completed. When we consider the capital advanced for such hazardous speculations—the peculiar difficulties of the times—the immense augmentation of parochial and government taxes—with the employment they have given to thousands of merchants, manufacturers, tradesmen, artificers, and workmen, we cannot but admire the mind that projected and carried into effect so many novelties, and ventured upon such a large amount of expenditure."

Mr. Cubitt subsequently further engaged to cover the vast open district lying between Eaton-square and the Thames, now known as South Belgravia. He also carried out similar operations at Clapham Park, a large open tract of land, 250 acres in extent, about four miles south-west of London. This he leased of Mr. Atkins Bowyer, the lord of the manor, and distributed it in lots for detached mansions and villas on a large scale. He formed wide roads, four miles in extent, purchasing adjacent property to enable this to be systematically accomplished. He commenced building large mansions, and invited the public to take sites for others; and from that time to the present these works have been continued, until the whole ground is now nearly covered.

At a later period Mr. Cubitt had the honour of being sent for by Her Majesty, to advise upon the alterations of the house at Osborne, in the Isle of Wight, and he eventually designed and constructed the new marine residence there, to the entire satisfaction of Her Majesty. He was also employed to build the east front of Buckingham Palace, and other works of magnitude connected with the Crown.

Mr. Cubitt felt a deep interest in the question of the sewage of the Metropolis, and in 1843, he wrote a pamphlet for private circulation, advocating the views on the subject now become general. These were afterwards embodied in a letter to the "Times," when the

subject began to attract general interest. He took great pains to stop the smoke nuisance from large steam chimneys, and completely effected this object at his extensive factory at Thames Bank, which he had erected after leaving the establishment in Gray's Inn Road. He was a great advocate for leaving open spaces, for recreation, in the midst of London; and took a principal part in the plan of Battersea-park, of which he was one of the originators. When the scheme was attacked by Mr. Disraeli, then Chancellor of the Exchequer, he offered to buy the whole of the land and the bridge, from the Government, at the sum they had expended upon it. Anticipating a great increase in the size of London, he urged several times, on the Government of the day, the policy of buying tracts of unoccupied land along the river banks above London, in order that they might be devoted to public parks, before the value had become great, from the increase of building. In the embankment of the Thames above Vauxhall-bridge, he was the principal mover, and constructed about 3,000 feet at his own expense, adjacent to South Belgravia.

From his long experience of building, and great practical knowledge of all its details, his advice was constantly sought by various branches of the Government, on questions of this nature. He was frequently examined by Committees of the House of Commons on the same subject, and took a leading part in the preparation of the late Building Act. He gratuitously undertook the negotiation for the purchase of the property at Brompton, on behalf of the Commissioners of the Great Exhibition of 1851, for which he was well qualified, from his great experience in such transactions, and to this he devoted a great deal of time in the latter years of his life. He was also one of those who guaranteed a sum of money to carry on the Exhibition of 1851, when its success was doubtful.

Shortly after the commencement of his great undertakings, a monetary panic occurred, which caused almost general ruin, but his undaunted courage and perseverance carried him through the difficulties which arose from it. To accomplish his multifarious works, sometimes with urgency and rapidity—at others, with caution and apparent timidity—required unabated vigilance and circumspection. At times, more than two thousand men were employed, all of whom had to be regularly paid, in addition to superintendents, clerks, and foremen, besides providing materials, and for the wear and tear of machinery. One instance of his equanimity, as well as his interest for his workmen, deserves to be recorded. When his premises at Thames Bank were burned down in 1854, and £30,000 worth of damage was done, his first words on hearing of the loss were, "Tell the men they shall be at work within a week, and I will subscribe £600 towards buying them new tools." Through life he was the real friend of the working man; and among his own

people he did much to promote their social, intellectual, and moral progress. He established a workman's library; a school-room for workmen's children; and, by an arrangement to have supplied to his work-people wholesome refreshments at low rates, did much to establish habits of temperance amongst them, in place of those of drinking which formerly existed. To those under him, and holding responsible situations, he was generous and kind, blending his position as master with that of a friend. He was a liberal benefactor to churches, schools, and charities, in those places with which he was connected, and always valued, in a peculiar degree, the advantages resulting to the poor from the London hospitals.

Mr. Cubitt joined the Institution as an Associate in the year 1839. He contributed two Papers to the "Proceedings;" one "Experiments on the Strength of Iron Girders,"[1] giving the results of experiments on sixty pairs of cast-iron girders, varying from 7 feet 6 inches to 27 feet in length; the other "Experiments on the Strength of Brick and Tile Arches,"[2] being the result of an investigation as to how the greatest amount of strength could be attained in fire-proof floors, with a due regard to the space occupied, and the cost of the structure.

He was much attached to the Institution, and constantly had recourse to it for information. His career was very eventful, and he was decidedly the pioneer of the great building establishments of the metropolis, and in the principal provincial cities and towns. Like the engineering contractors, the great builders have grown out of the peculiar wants of the period, and few men have gone through great labours and executed gigantic works with such equanimity as Mr. Thomas Cubitt. He deservedly accumulated very considerable riches, and acquired reputation, and at his decease, which occurred in his 68th year, at his seat, Denbies, near Dorking, on the 20th December 1855, he was surrounded by the members of his family, by whom, and by a large circle of friends, he was deservedly beloved and regretted.

MR. DAVID McINTOSH was born on the 16th of May, 1799, at Cheddleton, Staffordshire, and was the only child of the late Mr. Hugh McIntosh, the eminent Contractor. After receiving a liberal education, first, under the late Mr. Stock, of Poplar, where he was considered to be a mild and amiable boy, and was a great favourite with all his schoolfellows, and afterwards at the University of Glasgow, he assisted his Father in many extensive under-

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. i. (1841), p. 116.
[2] Ibid., p. 136.

takings. Besides this, he entered into, and completed, on his own account, many large contracts, among which the following may be mentioned:—in 1837 to 1841, three heavy divisions, comprising the Belper Contracts, on the North Midland Railway, under Mr. Stephenson, M.P., President;—from 1838 to 1841, the entire line between Rugby and Leicester, on the Midland Counties Railway, under Mr. C. Vignoles, M. Inst., C.E.;—from 1834 to 1838, the Dutton Viaduct, on the Grand Junction Railway, under the late Mr. George Stephenson;—from 1837 to 1841, three contracts on the London and South Western Railway, including the Southampton end, and the brickwork only of the London end, under Mr. J. Locke, M.P., V.P., and Mr. Giles;—from 1836 to 1840, five heavy contracts on the Great Western Railway, under Mr. I. K. Brunel, V.P.;—between 1838 and 1840, a portion of the Northern and Eastern Railway; and between 1834 and 1842, the Menai Lighthouse, extensive works at Dover Harbour, and the repairs of Blackfriars Bridge, under Mr. James Walker, M. Inst. C.E.; with the Portsmouth and Gosport Floating Bridge, under the late Mr. James M. Rendel, besides numerous other Public Works.

With the advantage of a liberal education, good natural talents, and an accomplished mind, he was well qualified to become a leading public man; but having, on his Father's death, in 1840, inherited a large fortune, and the works on which he had been engaged being near completion, he retired into private life. For some years, he suffered severely from disease of the heart, and he suddenly expired on the 7th January, 1856, much regretted by his many relatives and friends.

Mr. McIntosh was a very old Member of the Institution, having joined it as an Associate in the year 1825. His occupations prevented his frequent attendance at the Meetings, but he always evinced anxiety for the welfare of the Society.

LIEUTENANT-GENERAL DUNCAN MACLEOD, of the Bengal Engineers, the son of Donald Macleod, Esq., of Torbat, in the county of Ross, was born at that town on the 20th February 1780. In February 1797, he received an appointment as a Cadet of Infantry, on the Bengal Establishment, but was shortly afterwards transferred to the corps of Engineers at that presidency, and in 1806 was employed in making the Barrackpore and Pettah Ghaut Roads. In 1810, he was appointed superintendent of the new military road from Calcutta to Benares; and in the same year, was selected to survey the river Goomty, with the view of ascertaining the practicability of erecting an iron bridge over it. In the execution of this duty, he received the strongest expressions of the approbation of the Vizier of Oude, and at the earnest solicitation

of the Vizier, who desired the further aid of Captain Macleod's professional knowledge, not only in superintending the construction of the iron bridge over the Goomty, but also in the execution of some other works of importance, he was allowed to continue at the post, and to undertake the superintendence of the erection of the bridge. At the same time, in conjunction with another officer, he had the direction of the works of the new military road, an appointment which he resigned in 1813. In 1816, he became the agent for the manufacture of gunpowder at Ishapore; which post he held until 1820, when he was relieved from it, in consequence of his services being required with his corps.

In February 1822, he returned to Europe, to recruit his health, and while in England, he directed his attention to the processes employed in the manufacture of gunpowder; and with such effect, that on his return to India, in 1825, the government, at his recommendation, ordered very important modifications of the machinery for granulating powder, at the Indian factories.

In July of the same year, he was appointed superintendent of Nizamut buildings, at Moorshedabad. Having matured his plans, he submitted to the government of India, reports regarding the site and plan of the new palace, at Moorshedabad,[1] and the measures he would propose, for clearing and draining the interior of the Kella, and constructing new buildings, for the accommodation of the principal personages of the Nizamut. His plans were considered by the government eminently calculated "to promote the health, comfort, and respectability" of the Nizam, and the members of his family, and he was directed to carry them into effect. This palace is described in Roberts' "Sketches and Characteristics of Hindostan," as "a fine building, in the European style, of dazzling whiteness, and rising in glittering splendour, amid stately groves of flourishing trees."

The buildings in progress at Moorshedabad, were inspected by Colonel Sir Thomas Aubrey, chief engineer, in 1833, who says in his report;—"I have not during my fifty years' service, (and I trust that the experience I have gained in that time will obtain for me some credit,) seen such work as Colonel Macleod has executed in the erection of this grand building (the palace) either for the superior excellence of the materials, correctness of the workmanship, and the very beautiful external appearance of the walls and the structure altogether:—the sharp and neat finishing of the masonry, and its regularity of joints, would almost admit of dispensing with plastering, but for the description of the edifice, which without a coating, would be incongruous, and more espe-

[1] The model of which is now deposited in the Palace at Hampton Court.—EDITOR.

cially from its peculiar and singularly beautiful architectural character." This report was submitted to the government of India, by the Military Board, with the expression of their opinion, that it was "highly favourable to Colonel Macleod as an architect and builder of the first order."

The palace was completed in the year 1836. In noticing the opinion given by a committee, specially appointed to inspect the work, its plan and execution, that they were "highly honourable to the professional abilities of Colonel Macleod," the Court of Directors observed:—"The credit due to that officer is the greater, as, with the exception of one young officer, Lieutenant Cunningham, who was placed at his disposal, during a small portion of the time, in consequence of his own unavoidable absence, he had no European assistance, and the building was, as he says, designed and executed by himself, entirely through the agency of natives. We consider it a circumstance of no little importance, that the possibility of executing work of such a description, by native agency, has been established, and we trust, that the experiment so successfully made, will be a source of much saving of expense, hereafter, in the department of public buildings, as well as of permanent benefit to India, by training the native workmen to the highest description of skilled labour, in this important branch of industry."

Whilst engaged on this duty, an experiment suggested by him, for turning the current of the river Bhagruttee into its original channel, in order to protect the city from encroachment, was tried. In noticing the failure of the experiment, the government of India observed:—"It is a subject of regret, that so considerable an outlay should have been made, without full corresponding benefit, the method adopted for turning the channel of the river having failed. But the government were convinced, that reliance might be placed on Colonel Macleod's professional skill, not to suggest what would not present the best assurance of success that could be commanded." In 1830, he was appointed a member of a committee to report on the practicability of keeping the river Bhagruttee open. In November 1831, this committee furnished a report, containing much valuable information, regarding the Nuddeea rivers, and suggesting the construction of a canal, from Rajmahal, on the Ganges, to Mirzapoor, on the Hooghly. In consequence of this report, Colonel Macleod was ordered, in conjunction with Captain Forbes, to examine the country between Rajmahal and the Hooghly, with a view to determine the line for surveys, in order to judge of the practicability of forming the canal.

In 1836, he became a member of a committee, for considering a plan for the protection of the embankments of rivers. In 1837, he served on a committee, for preparing appropriate designs, for the insignia of the Order of British India, and the Order of Merit, and

in, 1839, he was appointed President of a committee, to report on the practicability of establishing steam floating-bridges across the river Hooghly, at Calcutta.

General Macleod finally left India in February 1841, and, in the following year, became an Associate of this Institution, to which he was naturally attracted, by his long and constant practice of engineering duties in India. He frequently attended the Meetings, and urged on all the junior officers of his corps, the necessity of paying marked attention, while in this country, to the construction and design of any public works which might be in progress, with a view to their being enabled, satisfactorily, to hold engineering appointments in the East. His death occurred on the 8th June 1856, in the seventy-seventh year of his age. As an officer he was greatly admired and respected, and in private life his kindness and uprightness of conduct induced the affection of his relatives and intimate friends, and commanded the esteem of all who had the good fortune to know him.

The dates of his commissions in the Engineer Corps were—Second Lieutenant, 28th November 1795; First Lieutenant, 13th November 1803; Captain, 9th February 1810; Major, 1st December 1826; Lieut.-Colonel, 28th September 1827; Colonel, 18th June 1831; Major-General, 23rd November 1841; and Lieut.-General, 11th November 1851.

MR. JOHN FLETCHER MILLER was born on the 20th of June 1816, at Whitehaven, in Cumberland, where his ancestors had resided for several generations. He received a good classical and mathematical education, at a seminary, at Kendal, formerly directed by Dr. John Dalton, but then under the management of Mr. S. Marshall. From boyhood Mr. Miller was essentially devoted to scientific pursuits, and at the age of fifteen years, he began a local meteorological register, which was continued, almost uninterruptedly, up to the period of his death. In this register he recorded the weight and temperature of the air, the fall of rain, and the force and direction of the wind; and to these particulars he afterwards added, hygrometrical observations on the absolute amount of surface evaporation, which was measured daily for many years,—the determination of the dew point, both by observation, and empirically,—the radiation of heat from the earth's surface at night,—and the radiating powers of various substances. Each of these departments of meteorology was investigated by extensive series of experiments, and the results, with his remarks upon, and conclusions deduced from them, were published in the "Philosophical Transactions," or embodied in the series of reports on

climate, which he annually furnished, for a long period, to the "Edinburgh Philosophical Journal."

In 1844, he began, at his own expense, an extensive series of experiments "On the fall of Rain in the English Lake District," and for many years had between twenty and thirty rain guages in operation. Early in 1846, he extended the inquiry to the mountains, with the view of ascertaining the gradation, and amount, of atmospheric precipitation, at various heights above the sea level, up to the highest attainable elevation in England. During seven years, he had pluviometers stationed at various heights on the mountains, from 600 feet above the valley, up to the summit of Sca Fell Pike, (the highest English mountain,) which is 3,166 feet above the sea level. For several years, he also obtained numerous observations, on the minimum temperature at night, at 1,900 feet, 2,925 feet, and 3,166 feet above the sea level; and on the relative humidity of the air at all the mountain stations. The results of these observations formed his concluding paper "On the Meteorology of the Lake District" for the years 1851, 1852, and 1853, which was communicated to the Royal Society of Edinburgh, on the 1st of May 1854, and was published in their Transactions. The inquiry into the "Meteorology of the English Lake District" has induced many interesting scientific results, some of which may be mentioned. It has shown, that there is a tropical fall of rain in the temperate zone, and that, in some portions of the lake district of England, the annual quantity amounts, occasionally, to 180 inches. That the fall, in a single month, at several stations in the lake district, in very wet seasons, considerably exceeded 30 inches, as was the case at Seathwaite, Gatesgarth, and Langdale Head, in December 1853. That the maximum fall, in twenty-four hours, is nearly 7 inches, and in forty-eight consecutive hours nearly 10 inches. These quantities, especially the annual fall, are, it is believed, unprecedented over the globe, except on some of the mountain ranges of India. The maximum fall of rain is found at, or about, 2,000 feet above the sea level, above which, the quantity rapidly diminishes.

Early in 1847, the Council of the Royal Society of London expressed a wish, to contribute towards the heavy annual expenses, attendant on an inquiry of such deep scientific interest. The first grant was accompanied by a request, that, as early as convenient, after the close of the current year, Mr. Miller would transmit to the Royal Society, a resumé of all that he had done, in that department of meteorology. The results then obtained were embodied in a paper, which was read before the Royal Society, on the 18th of May 1848. This paper was annually followed up, to 1854, by others on the same subject, and so highly were they esteemed, that, in June 1850, Mr. Miller was elected a Fellow of the

Royal Society, and five consecutive papers were published in the Philosophical Transactions. In 1850, he laid before that body a paper on "The relation of the Air and Evaporation Temperatures, to the Temperature of the Dew Point, as determined by the Greenwich Tables, computed by Mr. J. Glaisher, F.R.S., and by actual observation with a Daniell's Hygrometer."

For many years, Mr. Miller devoted much time to the study of astronomical science, and, in 1849, he founded an observatory, which he furnished with an equatorially-mounted refracting telescope, with wire micrometer, chiefly for the purpose of re-examining the principal double and binary stars. With this instrument, he executed a series of measurements, of the position and distances of a selected list of double stars. Much time and great care were bestowed upon these observations, as the object was to secure the utmost attainable accuracy in the results, rather than to collect a large number of imperfect observations, so that they might be used as elements in computation of the Stellar orbits. The results were published, from time to time, in the "Astronomie Nachrichten," and in the monthly notices of the Royal Astronomical Society. Double-star astronomy is admitted to require a greater amount of personal skill and dexterity, than any other branch of practical astronomy, and it is believed that Mr. Miller's measurements in this department, have not been surpassed, in accuracy, by any other observer. He occasionally delivered courses of lectures, on astronomy and the correlative sciences, in his native town, at the request of his fellow-townsmen, being ever ready to aid in the instruction of those who were less advanced in science than himself; and his observatory was always accessible to any who desired to avail themselves of its advantages.

Whilst, from their character, Mr. Miller's works and attainments will scarcely become very generally known, they have found acceptance, and just appreciation, among men of science. He maintained an extensive correspondence with the leading meteorologists of the day, amongst whom he was looked upon as one of the most eminent. He was a man of great and singular endowments, and his love of science was all-pervading. He possessed almost a professional knowledge of anatomy and medicine, to the study of which he devoted himself with intense assiduity; and so recently as October 1855, he entered himself at Guy's Hospital, with the intention of qualifying himself, legally, for the profession. For chemistry, also, from childhood, he showed a great predilection. His unwearied devotion to science, and its practical results, is the more remarkable, from the extreme delicacy of his health, for he scarcely had a day's freedom from pain after attaining his sixteenth year; and his close mental application was, frequently, only a refuge from intense physical suffering. In October 1837, in

the hope of benefiting his health, Mr. Miller took a voyage to Sydney, New South Wales, *viâ* Bahia, remaining at the former place some months. From thence, he proceeded to Valparaiso, Chili, returning to England early in January 1839. His love of science was evinced as strongly on sea as on land, for during his voyages out and home, he kept up daily three sets of meteorological observations, together with a journal of all interesting phenomena, with a ship's and private journal. Previous to sailing from London, he was elected a Member of the then existing Meteorological Society, with a request from the Council, that he would forward communications, as opportunity offered.

For some time previous to his decease Mr. Miller was occupied in collecting materials for a "Physical Geography of the English Lake and Mountain District," which it was proposed should embrace its geology, botany, ornithology, and entomology, in connection with observations on the climate and elevation, and the aërial phenomena peculiar to mountain localities. It was intended, that special attention should be given to the plants and insects (*Lepidoptera*) indigenous to the mountain regions: the English lake district presenting a rich field for research in these interesting departments of science.

Amid his scientific labours Mr. Miller found time to keep pace with the literature of the day, in which he was as well versed, as in that of the past. His love of Nature and her works was unbounded; even the humblest flower pressed beneath his foot, arrested his attention, and in all things he was fond of tracing the evidence of design and of adaptation, in the works of the outward creation. His attachment to his native county amounted to enthusiasm, and great was his delight when, in his numerous excursions, among the hills and mountains, he had the society of a sister, or a friend, with whom he could converse on the beauties around.

Mr. Miller, to those who were but slightly acquainted with him, appeared distant and reserved, but in the social and domestic circle he was ever the centre of attraction, being always ready to communicate, from his richly-stored and highly-cultivated mind, whatever he believed would afford either pleasure, or instruction. This he did in a manner so lucid, simple and unassuming, as almost to appear that he was himself the recipient of the benefit conferred. He was of a refined and pure nature, unaffected in disposition, amiable and benevolent, and possessing the warmest affections; whilst he was characterized from childhood by great love of truth, and strict integrity.

He expired on the 14th July 1856, having just completed his fortieth year. Mr. Miller became an Associate of the Institution of Civil Engineers in 1851, and to mark the appreciation of the Institution, of the value of his scientific observations, he was

almost immediately named a Life Associate of the Society. In addition to being a Fellow of the Royal Society, he was a Doctor of Philosophy, and Master of Arts of the University of Göttingen; Fellow of the Royal Astronomical Society; Member of the British Meteorological Society, and Corresponding Member of the Literary and Philosophical Society of Manchester, besides holding honorary rank in many other societies.

Mr. ROBERT WILKINS was born in the year 1779, and received his education in London. In conjunction with his senior partner, Mr. Robinson, he altered the method of illuminating the Edystone Lighthouse, from candles to reflectors, and was extensively employed by the Trinity Corporation in the manufacture of lanterns and lighting apparatus for the lighthouses and light-vessels of the coast. When that body tardily adopted the dioptric and catadioptric system of M. Fresnel, in the place of the Trinity-House reflectors, introduced by the late Captain Huddart, Mr. Wilkins was almost exclusively intrusted with their construction. The Start Point Lighthouse was one of the first at which Fresnel's apparatus was adopted, in England, and, about the same time, a nearly identical arrangement was adopted for the lighthouse at St. Katharine's, in the Isle of Wight; the lenticulated portions of the apparatus being principally obtained from Paris. Mr. Wilkins also constructed the light-apparatus and lantern at Europa Point, Gibraltar, the present improved lanterns, gimble-lamps, and reflectors for floating-lights, and the lights at the South Foreland, where the low light is on Captain Huddart's principle, and the high light is on the system of M. Fresnel. The mechanism of these lights is of a high order, and the management easy; it may be taken as a fair specimen of the workmanship which generally issued from Mr. Wilkins' manufactory. He was also employed in the construction of the lighting-apparatus of several of the lighthouses for the Colonies, as well as for foreign Governments, in all instances giving perfect satisfaction.

Mr. Wilkins joined the Institution as an Associate in the year 1843, and frequently attended the meetings. He was a good mechanic, intelligent in seizing the ideas of the Engineers under whom he was employed, and very conscientious in the execution of the work intrusted to him.

PREMIUMS AWARDED.

SESSION 1855-56.

THE COUNCIL of the Institution of Civil Engineers have awarded the following Premiums:—

1. A Telford Medal, and a Council Premium of Books, suitably bound and inscribed, to John Murray, M. Inst. C.E., for his paper "On the Progressive Construction of the Sunderland Docks."
2. A Telford Medal, to John Mortimer Heppel, M. Inst. C.E., for his paper "On the relative proportions of the Top, Bottom, and Middle Webs of Iron Girders and Tubes."
3. A Telford Medal, to Henry Robinson, Assoc. Inst. C.E., for his paper "On the Past and Present Condition of the River Thames."
4. A Telford Medal, to Charles Robert Drysdale, Assoc. Inst. C.E., for his paper "On Steep Gradients of Railways, and the Locomotives employed."
5. A Telford Medal, to Frederick M. Kelley, (New York, U.S. America), for his paper "On the Junction of the Atlantic and Pacific Oceans, and the practicability of a Ship Canal, without Locks, by the Valley of the Atrato."
6. A Council Premium of Books, suitably bound and inscribed, to George Herbert, for his paper "On the Construction of Buoys, Beacons, and other Stationary Floating Bodies."
7. A Council Premium of Books, suitably bound and inscribed, to Evan Hopkins, for his paper "On the Vertical Structure of the Primary Rocks, and the general character of their Gold-bearing Varieties."
8. A Council Premium of Books, suitably bound and inscribed, to John William Heinke, for his paper "On Improvements in Diving Dresses, and other Apparatus for Working under Water."
9. A Council Premium of Books, suitably bound and inscribed, to Joseph Baillie, (Pesth, Hungary,) for his paper "On the Application of Volute Springs to the Safety-valves of Locomotive and other Boilers."
10. A Council Premium of Books, suitably bound and inscribed, to William Kemble Hall, (U.S. America,) for his paper "On the Causes of the Explosions of Steam Boilers."

SUBJECTS FOR PREMIUMS.

SESSION 1856-57.

THE COUNCIL invite communications on the following, as well as other subjects, for Premiums:—

1. On the Principles upon which the Works for the Improvement of River Navigation should be conducted, and the effects of the works upon the Drainage and Irrigation of the District; including accounts of the Systems of Moveable Dams ('Barrages Mobiles') in Rivers on the Continent.
2. The Inundations of the Rhone and the Saone in the year 1856, the causes to which they may be attributed, and the means for averting their recurrence.
3. On Reclaiming Land from Seas and Estuaries.
4. The main Natural and Artificial Drains of the Country, the extent to which they have been affected by the increasing amount of Agricultural Land Drainage, and the general influence upon the main river outfalls.
5. The selection of Sites for the Construction of Docks on the course of Tidal Streams, with reference to communication with Railways, and with Inland Navigation.
6. The application of Wrought Iron to the Construction of Dock Gates and Caissons.
7. The selection of Sites for, and the principles of, the construction of Breakwaters and of Harbours of Refuge; and of Piers, Moles, (whether solid, or on arches,) Seawalls, and Shore Defences; illustrated by examples of known constructions.
8. The history and practical results of Timber and Iron Piling, for Foundations, or other purposes, and for Wharf and Dock Walls; with notices of mechanical modes of driving, and of other modes of inserting the piles.
9. Accounts of the failure of Large Structures consisting of one, or more Arches, with the presumed, or ascertained causes.
10. The laws of the Strength of Cast and Wrought Iron, under the various conditions of Tensile, Compressive, Transverse, Tortional, Impulsive, and other Strains; with examples illustrative of the coefficients employed by eminent practical authorities, in the construction of works.
11. The forms and dimensions of Journals of Machine-shafts, Axles, &c.; with the best Composition for the linings of bearings, and the most approved methods of lubricating.

12. The construction and use of Wrought Iron Girders and Joists, with arches, iron plates, concrete, or other incombustible substances, for buildings.
13. The construction of Suspension Bridges with Rigid Platforms; their adaptation to Railways, and the modes of Anchoring the Stay Chains.
14. The comparative advantages of Iron and Wood, or of both materials combined, for the construction of Steam Vessels, with drawings and descriptions;—the methods for preventing corrosion:—and details of the arrangements for the Compasses, and for their adjustment in Iron Ships.
15. The substitution of Machinery for manual labour, for Raising, Lowering, and Reefing the Sails, Weighing the Anchor, &c., on board ship.
16. An examination of the circumstances which appear to limit the maintenance of higher speeds, than are now attained by Steam Ships in deep-sea navigation; and an inquiry into the causes which have hitherto prevented the asserted high speeds of Steam Navigation, on the American Rivers, from being arrived at in England.
17. The results of the use of Tubular Boilers, and of Steam at an increased pressure, for Marine and other Engines, noticing partioularly the difference in weight and speed, in proportion to the Horse Power and the Tonnage; with details of the most successful means for avoiding Smoke in Furnaces of all descriptions.
18. The best methods of reducing the temperature of the Engine and Boiler room of Steam Vessels, and of preventing the danger arising from the over-heating of the base of the funnel.
19. The relative efficiency of the Screw Propeller and Paddle Wheels, when applied to vessels of identical form, tonnage, and steam power, independent of the use of sails.
20. The arrangement and distribution of the Workshops at the principal repairing station of a Railway, for the repairs and maintenance of the Locomotives, Passenger, and other Carriages, &c.; derived from existing examples.
21. The comparative merits of the various systems of Locomotive Engines; having reference to the speed, the load conveyed, the economy of working, and the fuel employed, whether Coke, Bituminous Coal, or Anthracite.
22. The use of Steam expansively in Locomotive Engines, and the different systems of gearing employed.
23. The principles of construction, the framing, the boiler, the distribution of weight, and the conditions of stability of Locomotive Engines.

24. Improvements in the Manufacture of Iron for Rails and Wheel Tyres, having special reference to the increased capability of resisting lamination and abrasion; and accounts of the Machinery required for rolling heavy Rails, Shafts, and Bars of Iron of large sectional area.
25. On the Cost of Maintenance of the Permanent Way; noticing the principal systems in use, whether with Wood, or Iron Sleepers, and the depreciation of the Rolling Stock of Railways.
26. Improvements in the construction of Railway Carriages and Waggons, with a view to the reduction of the gross weight of Passenger Trains; also of Railway Wheels, Axles, Bearings, Axle-Boxes, and Breaks; treating particularly their ascertained duration and their relative friction.
27. The forms of bearing, traction, and buffer Springs of Railway Carriages and Waggons.
28. Description of the peculiarities of construction, and the cost of the Lines of Railway in India,—in Egypt,—in Australia,—in Canada,—and across the Isthmus of Panama.
29. On Public Works in India.
30. The results of a series of observations on the flow of Water from the Ground, in any large districts; with accurately-recorded Rain-Gauge Registries, in the same locality, for a period of not less than twelve months.
31. On the construction of Catch-water Reservoirs in Mountain Districts, for the supply of Towns, or for manufacturing purposes.
32. Accounts of existing Water-works; showing the methods of supply, the distribution throughout the streets of Towns, and the general practical results.
33. The comparative duty performed by the various descriptions of Steam Engines for raising Water, for the Supply of Towns, or for the Drainage of Mines; noticing, in the latter cases, the depth and length of the underground workings, the height of the surface above the sea, the geological formation, the contiguity of streams, &c.
34. The results of the use of Bucket and Rotary Pumps, for lifting large quantities of water to a limited height; as at the Haarlem Meer, or at Whittlesea Mere: with descriptions of the Machinery employed.
35. The Drainage and Sewerage of large Towns; exemplified by accounts of the systems at present pursued, with regard to the level and position of the outfall, the form, dimensions, and material of the Sewers, the prevention of emanations from them, the arrangements for connecting the house-drains with the public Sewers, the disposal of the sewage,

whether in a liquid form, as irrigation, or in a solid form after deodorization.

36. The precautions adopted for guarding against Accidents by Fire-damp in Mines.
37. Mechanical Methods of Boring and of Sinking large Shafts, of introducing the Tubbing and impervious lining, and of traversing running sand, and other difficult strata.
38. The results of contrivances for facilitating the driving of Tunnels, or Drifts, in Rock.
39. Descriptions of the various kinds of Machinery in use in the principal Shipping Ports, for the shipment of Coal; noticing particularly those in which the greatest expedition is combined with the least amount of breakage of the Coal; and also accounts of the means of unshipping, and measuring, or weighing the Coal, on its arrival in port.
40. Descriptions of the Ovens, and of the best processes used in Great Britain, and on the Continent, in the manufacture of Coke for Railway and other purposes; with the comparative values of the products.
41. Improvements in the system of Lighting by Gas; the results of the use of Clay Retorts,—of large Ovens (for producing a better quality of Coke,)—of Exhausters, Condensers, and modes of Purifying, and the precautions for the economical distribution of Gas.
42. The most effective arrangement and form of Centrifugal and Reciprocating Blowing Apparatus.
43. The Chemical Analysis, and the application to economic purposes, of the Gases generated in Iron Blast Furnaces.
44 Descriptions of modifications of the present systems of Smelting Iron Ores, of improvements in the conversion of cast iron into the malleable state, and of the manufacture of iron generally, comprising the distribution and management of Iron Works.
45. An investigation of the causes of "Red" and of "Cold-Shortness" in Malleable Iron, and other Chemical Characteristics which affect the Physical Properties of Cast, or of Wrought Iron.
46. An investigation of the changes stated to be produced in large masses of Wrought Iron, by repeated heating and hammering.
47. The production of large masses of Cast Steel, with a description of the improved processes for converting Cast Iron into Cast Steel, and the modes of treatment to insure soundness.
48. Improvements in the methods of Shearing, and Punching Sheet Iron, and Boiler Plates.
49. The process of manufacture, and mode of treatment of Aluminium.

50. Mechanical Improvements in Ordnance, and Projectiles.
51. Description of Cast, or Wrought Iron Cranes, Scaffolding and Machinery, employed in large works, in Stone Quarries, Hoists, or Lifts on Quays, in Warehouses, &c., especially where either Steam, or Water is used as a motive power.
52. Improved processes and Machinery for sawing, working, and carving Timber, or Stone.
53. On the Improvements which may be effected in the Buildings, Machinery, and Apparatus for producing Sugar from the Cane, in the Plantations and Sugar-works of the British Colonies, and the comparison with Beet-root, with regard to quantity, quality, and economy of manufacture.
54. Accounts of the improved systems of storing, cleansing, and drying Corn, and of producing Flour.
55. Description of the Machinery adapted for the preparation of Indian Cotton.
56. Improvements in Flax Machinery, and in the processes for preparing the Flax for manipulation.
57. The uses of Vulcanized Caoutchouc in Machines; the means of increasing its durability, and the modes of causing its adhesion to metal.
58. Notice of the principal Self-acting Tools employed in the manufacture of Engines and Machines; and the effect of their introduction.
59. The construction of Lighthouses; their Machinery and Lighting Apparatus: with notices of the methods in use for distinguishing the different Lights..
60. The construction of Clocks to be moved simultaneously by the agency of Galvanic Electricity.
61. The History of the Submarine Telegraph; with accounts of the mode of forming the cable, the system of laying it down, and of working it over great lengths.
62. Memoirs and accounts of the Works and Inventions of any of the following Engineers:—Sir Hugh Middleton, Arthur Woolf, Jonathan Hornblower, Richard Trevithick, William Murdoch (of Soho), Alexander Nimmo, and John Rennie.

Original Papers, Reports, or Designs, of these, or other eminent individuals, are particularly valuable for the Library of the Institution.

The communications must be forwarded, on or before the 30th of January 1857, to the house of the Institution, No. 25, Great George Street, Westminster, where copies of this paper, and any further information may be obtained.

CHARLES MANBY, *Secretary.*

25, *Great George Street, Westminster,*
20th October, 1856.

NOTICE.

It has frequently occurred, that in Papers which have been considered deserving of being read and published, and have even had Premiums awarded to them, the Authors may have advanced somewhat doubtful theories, or may have arrived at conclusions at variance with received opinions. The Council would, therefore, emphatically repeat, that the Institution must not, as a body, be considered responsible for the facts and opinions advanced in the Papers, or in the consequent Discussions: and it must be understood, that such Papers may have Medals and Premiums awarded to them, on account of the Science, Talent, or Industry displayed in the consideration of the subject, and for the good which may be expected to result from the discussion and the inquiry; but that such notice, or award, must not be considered as any expression of opinion, on the part of the Institution, of the correctness of any of the views entertained by the Authors of the Papers.

EXTRACTS FROM THE MINUTES OF COUNCIL, FEB. 23rd, 1835.

"The principal subjects for which Premiums will be given, are—

"1st. Descriptions, accompanied by Plans and explanatory Drawings, of any work in Civil Engineering, as far as absolutely executed; and which shall contain authentic details of the progress of the Work, (Smeaton's Account of the Edystone Lighthouse may be taken as an example.)

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INSTRUCTIONS FOR PREPARING COMMUNICATIONS.

The Communications should be written in the impersonal pronoun, and be legibly transcribed on foolscap paper, about thirteen inches by eight inches, the lines being three-quarters of an inch

apart, on the one side only, leaving a margin of one inch and a half in width on the left side, in order that the sheets may be bound.

The Drawings should be on mounted paper, and with as many details as may be necessary to illustrate the subject, and should be to such a scale that they may be clearly visible, when suspended on the walls of the Theatre of the Institution, at the time of reading the communication; or enlarged Diagrams may be sent for the illustration of any particular portions.

Reduced Drawings for the illustrative Plates and Woodcuts will be required, as soon as the papers are accepted.

Papers which have been read at the Meetings of other Scientific Societies, or have been published in any form, cannot be read at a Meeting of the Institution, nor be admitted to competition for the Premiums.

EXCERPT BYE-LAWS, SECTION XIV., CLAUSE 3.

"Every Paper, Map, Plan, Drawing, or Model presented to the Institution, shall be considered the property thereof, unless there shall have been some previous arrangement to the contrary; and the Council may publish the same, in any way and at any time they may think proper. But should the Council refuse, or delay the publication of such paper, beyond a reasonable time, the Author thereof shall have a right to copy the same, and to publish it as he may think fit, having previously given notice, in writing, to the Secretary, of his intention. No person shall publish, or give his consent for the publication of any communication presented and belonging to the Institution, without the previous consent of the Council."

ORIGINAL COMMUNICATIONS,

DRAWINGS, PRESENTS, &c.,

RECEIVED BETWEEN JUNE 30, 1855, AND JUNE 29, 1856.

ORIGINAL COMMUNICATIONS.

AUTHORS.

Adams, W. B. No. 947. On the Varieties of Permanent Way, practically used, or tried, on Railways. With a series of Diagrams.

Bell, W. No. 945. On the Laws of the Strength of Cast and Wrought Iron. With one sheet of Diagrams.

Clark, D. K. No. 949. On the Improvement of Railway Locomotive Stock, and the Reduction of the Working Expenses. With a series of Diagrams.

Drysdale, C. R. No. 940. On Steep Gradients of Railways, and the Locomotives and Stationary Engines employed. With three Diagrams.

Hall, W. K. No. 936. On the Causes of the Explosions of Steam Boilers. With one Diagram.

Heinke, J. W. No. 935. On Improvements in Diving Dresses, and other Apparatus for working under water.

Heppel, J. M. No. 933. On the Relative Proportions of the Top, Bottom, and Middle Webs of Iron Girders and Tubes. With one Diagram.

Hopkins, E. No. 934. On the Vertical Structure of the Primary Rocks, and the general character of their Gold-bearing Varieties. With a series of Diagrams and Charts.

Kelly, F. M. No. 948. On the Junction of the Atlantic and Pacific Oceans, and the Practicability of a Ship Canal, without Locks, by the Valley of the Atrato. With a series of Charts and Sections.

Margary, P. J. No. 946. Description of a Method of removing Bridges, on the South Devon Railway, between Newton and Totnes, for the purpose of doubling the line.

Murray, J. No. 950. On the Progressive Construction of the Sunderland Docks. With a series of Diagrams.

Robinson, H. No. 938. On the Past and Present Condition of the River Thames.

CATALOGUE OF PRESENTS.

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[Printed by permission of the Council.]

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January 13, 1857.

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in the Chair.

The following Candidates were balloted for and duly elected:—HOWARD JOHN KENNARD, THOMAS WILLIAM KENNARD, THOMAS LAMBERT, FREDERICK LAWRENCE, EDWIN MARSHALL, EDWARD BINDON MARTEN, JOSHUA DEWER MATHEWS, and STEPHEN MOULTON, as Associates.

No. 952.—"On Submarine Electric Telegraphs.."[1] By FREDERICK RICHARD WINDOW, Assoc. Inst. C.E.

THE rapidly-extending system of submarine and international communication has now assumed so much importance, and forms such a prominent feature in the daily transactions of life, that a short review of the subject, in an engineering point of view, must be interesting to the Institution; although the Author regrets, that no one abler than himself has undertaken the task.

This invention,—for connecting lands which Nature herself has separated with her most formidable barrier, and for linking together remote kingdoms in the common chain of civilization,—is a very modern discovery: yet so rapidly has it spread throughout Europe, that, from constant use, and familiarity with its manifold advantages, it has become, within a few years, a material fact, indispensable for our convenience and happiness, and is now an absolute necessity. Like the Electric Telegraph itself, its parentage is difficult to trace. It was the emanation of no single brain, but had been a cherished dream, from an early date in the era of electric telegraphy, the probable realization of which every one admitted, although the means for its accomplishment were still unknown.

The first mention, that the Author has been able to find, of any method of so sufficiently insulating wires, as to enable them to conduct an electric current, when submerged in water, is in an account of some experiments made by Dr. (now Sir W. Brooke) O'Shaughnessy, at Calcutta, in the summer of 1839, and described by him, in the "Journal of the Asiatic Society,"[2] in the following terms:—"Insulation, according to my experiments, is best accomplished by enclosing the wire, (previously pitched,) in a split ratan,

[1] The discussion upon this Paper occupied portions of three evenings, but an abstract of the whole is given consecutively.

[2] *Vide* "Journal of the Asiatic Society, Calcutta," No. 93. September, 1839.

and then paying the ratan round with tarred yarn; or the wire may, as in some experiments made by Colonel Pasley, at Chatham, be surrounded by strands of tarred rope, and this by pitched yarn.

"An insulated rope of this kind may be spread along a wet field, nay, even led through a river, and will still conduct, without any appreciable loss, the electrical signals above described."

This was actual experiment, probably only on a small scale, but it is positive evidence.

In 1840, before a Committee of the House of Commons,[1] Professor Wheatstone, in reply to a question from Sir John Guest, stated that there would be no difficulty in passing the telegraph line through water, but that the experiment had not been tried. The Chairman, Lord Seymour, then asked, "Could you communicate from Dover to Calais in that way?" to which the Professor replied, "I think it perfectly practicable." In the "Bulletin de l'Académie Royale des Sciences de Bruxelles" of October 17th, 1840, it is announced, that Mr. Wheatstone had discovered a means of insulating wires, so as to place Belgium in telegraphic communication with England, and other countries; and the various advantages that might be expected to result from such an undertaking are enumerated.

From the present experience of the difficulties and requirements of submerged wires, it is a question, whether, at the date of these assertions, it would have been possible to lay down a wire, sufficiently well insulated to carry an electric current across the Channel; but the demonstration, a few years later, by Professor Faraday, of the excellent non-conducting qualities of gutta percha, and its fitness for insulating telegraph wires, furnished the means of realizing these schemes, at the exact period when such a discovery was required.

This vegetable production has long been well known, but has only lately been extensively employed commercially. It is peculiarly adapted for telegraph wires, as an insulating cover, whether for submarine, subterranean, or other and minor purposes. Tough, fibrous, flexible, and of easy manipulation; capable of being welded, or joined, of being moulded and compressed into any form, a non-conductor of electricity, capable of resisting acids, and any chemical action, and unaffected by sea-water; it would be difficult to imagine a substance better suited to aid the engineer, in forming electric communications.

A paragraph from an American newspaper states, that[2] "Colonel Colt was the first man who ever carried a telegraph under the sea.

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[1] *Vide* Minutes of Evidence, in the Fifth Report upon Railways.

[2] This paragraph was furnished by Colonel Colt, but there was no indication from whence it was taken, or of its date.—EDITOR.

Contrary to the advice of those who were at that time engaged in the telegraph, he undertook to carry a wire through Hell Gate to Fire Island; and contrary to their prognostication, he succeeded. Colonel Colt, at that time urged those interested to solicit this (the United States) Government to invite the British Government to join in the construction of a telegraph uniting the two continents; and that project, I see by the last steamer, is now mooted. From Dover to Calais, the same thing has been done more recently; yet here it is well known who first succeeded in that idea."

Lieutenant Siemens, of the Prussian Royal Artillery, is stated to have constructed, in 1848, a telegraphic communication under the Rhine, between Cologne and Deutz, a distance of about a quarter of a mile, by means of a wire covered with gutta percha.

The first recorded experiment in England, with gutta-percha-covered wires, immersed in the sea, was made off Folkestone Harbour, on the 10th January, 1849, by Mr. C. V. Walker, Telegraph Engineer to the South Eastern Railway Company. Upon that occasion, two miles of gutta-percha-covered wire were towed out to sea in an open boat; the ends of this wire were carried on board a steamer moored alongside the pier, and one of them was joined to a London wire; the other was connected to an instrument, and a communication was established between this latter and the earth, by hanging a copper plate, connected with it by a wire, overboard into the sea. All electric shocks, therefore, sent by the battery belonging to the instrument, had to pass along the submerged wire, on their passage to, or from London, and if the insulations had been imperfect, they could not have been deciphered upon the instruments, as "the earth," in this instance represented by the sea-water, would have been reached by the shorter circuit offered by the imperfections in the gutta percha. It was found, that the signals passed quite as well, as along a suspended wire; and many communications were sent between the steamer and London in the course of the day. This was a most important experiment, and the first of its kind.

In 1847, a concession was granted, for ten years, by the French Government to Mr. Jacob Brett, for a submarine telegraph between England and France: but it was allowed to lapse.

On the 10th August, 1849, a second concession (also for ten years) was again granted to Mr. Jacob Brett for the same purpose; and, in pursuance of the stipulation, in August, 1850, a copper wire, covered with gutta percha, about half an inch in diameter, was laid across the Channel, from a point on the English coast, near Dover, to Cape Grisnez, a headland in the vicinity of Calais. It was weighted, at intervals of about half a furlong, with lumps of lead, to prevent it from floating on the surface, as it would otherwise have done, owing to the low specific gravity of the gutta

percha. A few complimentary messages were sent between the two countries: but, on the following morning, when the engineers of the French Government arrived to inspect the wire, and to make their report, it was discovered that the communication was broken, and as they imagined that no telegraphic signals had ever been transmitted, they reported accordingly, and the concession was lost.

On the 23rd October, 1851, another concession, also for ten years, was obtained, in favour of Lord de Morley, the Honourable Frederick William Cadogan, Sir James Carmichael, and John Watkins Brett, and under this concession the Submarine Telegraph Company now works.

The probability of a submarine telegraphic communication between France and England still appeared to be remote. The scheme was disapproved of by several engineers in England, and all the French engineers declared it to be impossible. Contractors noted for their enterprise and liberality refused to undertake its construction, and the public, when applied to for funds through an excellent Direction, by means of a prospectus, subscribed only £300. The lapse of time allowed for the fulfilment of the conditions of the concession had but seven weeks to run.

Affairs were in this state, when application was made to Mr. Crampton, who was deeply interested, as a shareholder, in the undertaking. He professed confidence in the feasibility of the scheme, and engaged not only to put the mechanical and engineering portion in a practical shape, on his own responsibility, but to provide one-half of the necessary capital. In seven weeks the means and manner of carrying out an undertaking such as had never been known before were devised; the form of cable suitable to all the requirements of the case was decided upon; the machinery necessary for its manufacture was invented, designed, made, and erected; the cable itself was manufactured; and on the 25th September, 1851, it was laid at the bottom of the channel, with perfect success, notwithstanding that the vessels at Mr. Crampton's disposal were avowedly unfitted for the purpose, a circumstance which could not be avoided at the time, owing to the urgent need for despatch. It is thus probably owing to the energy, skill, and courage of Mr. Crampton, in adhering to his conviction of the practicability of a scheme which was almost universally condemned by the highest authorities as chimerical, that the public is indebted for the actual possession of a submarine telegraph. Indeed, subsequent events prove this, almost as much as the first fact of the successful completion of the Calais line. On finding that the cable had really been laid down, and that it continued, day after day, in a serviceable condition, submarine telegraphs began to be considered as a fact, and contracts were

entered into for the construction and laying down of other lines. However, three successive attempts were made to connect England and Ireland by a submarine telegraph, and in every case with signal failure. The first was between Holyhead and Dublin; the second and third, between Port Patrick and Donaghadee. All these cables were lost. Upon this, the success of the Calais line began to be looked upon as a lucky chance, not probably to be repeated; and Messrs. Newall, the Contractors for the Ostend cable, offered a large sum of money to be released from the responsibility of laying it down; but on Mr. Crampton, at the time one of the engineers of the Company, offering to undertake it, the operation was subsequently performed by the contractors with perfect success.

If the three above-mentioned failures had occurred before, instead of after the success of the Calais line, which clearly demonstrated the possibility of such an undertaking, it is a question whether, to this day, any submarine telegraph would have existed. The Author has, therefore, treated this portion of the subject at considerable length, because he considers, that in a treatise on the submarine telegraph, the name of Mr. Crampton should stand foremost, though the names of his assistant, Mr. Wollaston, and also those of Messrs. Statham, Wilkins, and Wetherly are deserving of honourable mention.

The cable laid from Dover to Calais in September 1851, consisted of four gutta-percha-covered copper wires, protected against the evils which had proved fatal to the first, by a coating of galvanized iron wires. This cable, which is about twenty-four miles in length, has remained perfect to the present time, and is still the medium of communication between the two countries.

In May, 1853, a cable of six wires, protected in a similar manner, was laid down, under a concession granted by the Belgian Government to the same Company, between Dover and Ostend; a distance of about sixty miles.

Early in 1853, "The Magnetic Telegraph Company" laid a very fine cable, of six wires, from Port Patrick to Donaghadee, with perfect success. The length is about twenty-four miles.

In May, 1853, a cable, consisting of one gutta-percha-covered wire, with a galvanized-iron wire coating, was laid by "The International Telegraph Company," (a branch of "The Electric Telegraph Company,") between England and Holland. The point of departure was Orfordness, in Suffolk, and that of arrival Scheveningen, a small fishing-town on the Dutch coast, three miles distant from the Hague. The length of sea-way was one hundred and fifteen miles. Two similar cables were added in the same year, and in 1855, the system was completed with a fourth. In August 1854, a cable of a like construction, about fifty-nine miles

long, was successfully laid, by the same company, between Holyhead and Howth.

The above are the chief submarine lines proceeding from this country; but the applications of the principle in the interior of the kingdom, including the passage of the Solent, several friths, navigable rivers, and canals, are very numerous, though they scarcely merit special mention.

An English company has also just laid a magnificent cable of six wires from Spezia to Corsica, the first portion of a line to connect the continent of Europe with the northern coast of Africa. The part completed is one hundred and ten miles in length, and the whole distance will exceed two hundred and fifty miles.

England having led the way in this kind of enterprise, the example was speedily followed by most of the European governments, who invariably keep the management of the electric telegraphs in their own hands. The Danish islands have been joined to the mainland, and rivers which had hitherto caused a break in several lines, have been crossed by submarine cables, most of which were constructed in England. America has also made extensive use of the invention, for passing her mighty rivers, and Prince Edward's Island has been connected with Newfoundland, by a cable of one hundred and fifty miles in length.[1] The system has also been advantageously introduced into India, and indeed wherever electric telegraphy is known.

It is a curious, though well-known fact, that all the great marine telegraphs have been laid down under peculiar difficulties, with regard to weather: as though Neptune resented this unwonted invasion of his territory. This was more particularly the case with the Calais cable, which was made to describe unexpected curves at the bottom of the Channel; and at one place, it was drifted some miles out of its course, the tug-rope having broken. The consequence was, when near to the coast of France, it was discovered that, from these causes, the wire would not reach the shore by half a mile; although four miles more than the actual distance had been put on board, to meet such a contingency. The necessary additional quantity of cable was, however, manufactured in a few days, and the line was satisfactorily completed.

The first Dutch wire, also, was laid down under very unpropitious circumstances. The expedition started from Orfordness in a calm, but before it had got sixty miles out to sea, it was saluted with half a gale of wind, which rapidly increased. The storm

[1] This cable is the first link of the proposed telegraphic communication between America and England.—EDITOR.

continued all night, with great violence, but the operation of paying out the cable was carried on unremittingly, and the expedition arrived off Scheveningen early in the morning, with a stiff north-west wind blowing, and a heavy rolling surf, through which no boat could with safety carry the end ashore. That operation was, therefore, postponed for some hours; yet, notwithstanding all these difficulties, the whole distance of one hundred and fifteen miles was traversed with less than one hundred and nineteen miles of cable.

There is but little to describe in the actual construction of a telegraph cable, "per se." The Calais cable is formed of four copper wires, of No. 16 W. G., carefully covered with two coatings of gutta percha, after having been twisted together into a rope, and served with spun yarn and hemp saturated with tar. The telegraph wires are generally thus twisted into a rope, instead of being laid straight in their iron coating, so as to afford greater facility for stretching without injury, in case of an unexpected strain on the cable. Round this core was spun an outer coating of ten iron wires of No. 1 W. G., or $\frac{5}{16}$ inch diameter, welded into lengths of twenty-four miles each; thus forming as it were a kind of flexible mail round the tender gutta percha. The manufacture of this cable occupied twenty-one days, and the whole, when completed, weighed 180 tons.

The following is a tabular description of the construction of some of the principal submarine cables now in existence, arranged chronologically, commencing with the first successful attempt to lay a cable, but omitting the experiment by Crampton and Wollaston, in August, 1850, from Dover to Cape Grisnez, and the subsequent failures:—(See page 195.)

It will be noticed, that the main idea, in all the above-mentioned cables, is the same: that is to say; a copper conducting wire is insulated from contact with other wires, or the earth, by two cylinders of gutta percha carefully applied round it, one over the other; and this insulating material is itself protected from outward abrasion, by a covering of iron wires—a layer of some soft substance, (as hemp,) being placed between them, to guard the surface of the soft gutta percha, from immediate contact with the hard metal. Very many modifications have been suggested by various inventors, but they have all been based upon the above principle, with the exception of a cable invented by Mr. West, in which India Rubber is substituted for Gutta Percha, which he considers is well suited for insulating submarine cables.

It may be remarked, that the cables laid down by the International Telegraph Company differ from all others of any importance, inasmuch as each conducting wire has its own separate coatings of gutta percha, tape, hemp, and iron wire, and forms a

Destination of Cable.	Engineer.	Maker.	Number of insulated Copper Wires.	Gauge of Copper Wires.	Number of Iron Wires.	Gauge of Iron Wires.	Length of Cable in Miles.	Weight per Mile.	When laid.
				No.		No.			
Dover to Calais	Crampton	Wilkins and Wetherly, and Newall and Co.	4	16	10	1	21	7 tons.	Sept. 25, 1851.
,, to Ostend	Crampton & Wollaston; & Reid	Newall and Co.	5	16	12	2	59	6¾ ,,	May 4, 5, 1853.
Portpatrick to Donaghadee	Bright	,,	6	16	12	2	24½	6¾ ,,	May, 1853.
Orfordness to Scheveningen, No. 1	E. Clark	,,	1	16	10	8	114½	2 ,,	May 30, 31, 1853.
,, ,, No. 2	,,	,,	1	16	10	8	114½	2 ,,	June 16,17, 1853.
Cronstadt to St. Petersburg	Siemens	,,	3	16	12	8	4½	..	Aug. 1853.
Orfordness to Scheveningen, No. 3	E. Clark	,,	1	16	10	8	114½	2 ,,	Sept. 8, 9, 1853.
Isle of Wight	L. Clark	,,	3	16	9	1	1	5 ,,	Nov. 10, 1853.
Granton to Burntisland, Frith of Forth	F. C. Webb	,,	4	16	40	8	5	8½ ,,	Dec. 22, 1853.
Across the Tay	,,	,,	4	16	40	8	1	8½ ,,	Dec. 24, 1853.
Spezia to Corsica	Physick and Thompson	Kuper and Co.	6	16	12	1	110	8 ,,	June, 1854.
Holyhead to Howth, No. 1	E. Clark	Newall and Co.	1	16	10	8	58½	2 ,,	Sept. 4, 5, 1854.
America and Newfoundland	None	Kuper and Co.	3	16	12	4	150	..	1855.
Balaklava and Varna	Liddell	Newall and Co.	1	16	None.	..	350	2¾ ,,	May, 1855.
18 miles at each end of ditto	,,	,,	1	16	9	8	36	34 cwt.	
Holyhead to Howth, No. 2	E. Clark	Fenton and Co.	1	16	10	8	58½	2 tons.	June 13, 14, 1855.
Orfordness to Scheveningen, No. 4	L. Clark	Newall and Co.	1	16	10	8	114½	2 ,,	Sept. 29, 30, 1855.
Varna and Constantinople	Newall	,,	1	16	12	12	180	18 cwt.	Oct. 1855.
Balaklava to Eupatoria	,,	,,	1	16	12	12	40	18 ,,	Oct. 1855.
Cape Breton to Newfoundland	None	Elliot and Co.	1	16	9	8	85	35 ,,	Aug. 1856.
West of Ireland to Newfoundland	Bright and Whitehouse	Kuper and Co. and Newall and Co.	7	20	126	20	1900	19 ,,	Not laid.

complete, independent cable of itself; whilst in all others, as many wires as are required are collected into a bundle, and enclosed together in one common hempen and iron coating. This innovation, which is due to Mr. E. Clark (M. Inst. C.E.), has both its advantages and disadvantages. The manufacture is simpler, and consequently the chances of imperfection are diminished. The weight, (in proportion to the length,) is less, and the whole is therefore more manageable, which is a very important fact in the difficult operation of laying down. This method, also, offers great facilities for repairing any damage that may happen to the cables, for every wire being independent of all the others, can be overhauled in its entire length, without useless labour, or fear of disturbing messages which may be passing on the perfect wires. On the other hand, these cables are certainly more liable to damage from ships' anchors, &c.; first, from the mere fact of there being many of them, instead of one; and secondly, because from their smaller section they are less capable of resisting a strain. This latter event has been partially guarded against by Mr. Clark, by twisting all the cables together into one, near the shore, upon shoals, in anchorage waters, and other places where such accidents are probable. The two methods do not materially vary in expense.

The actual laying down of a telegraph cable offers interesting details, which require to be treated in a separate Paper, based upon the account of some great enterprise, such as the Atlantic Cable; the Author has, therefore, preferred omitting, on the present occasion, all notice of these operations.

The passage of electricity by submerged wires, as compared with that by suspended wires of the same conducting capacities, presents phenomena well worthy of study, and which deserve to be minutely considered, before undertaking the construction of submarine lines of very great extent. If one pole of a battery be connected with the earth, and the other pole be connected, (through a galvanometer, or coil,) with either end of a submerged wire, a rush of electricity into the wire will instantly take place, and be noted by a deflection of the galvanometer needle. But soon, although contact with the battery be continued, the deflection will cease, except such few degrees as are due to leakage, or the actual conducting power of the gutta percha. If the battery pole be then removed, and the end of the water wire put to earth, the electricity will rush out of the wire, and the galvanometer needle will be deflected in the opposite direction. These effects of charge are not observed in a suspended wire, in which the degree of deflection, owing to defective insulation, is alone shown, and that immediately.

Professor Faraday, in a lecture at the Royal Institution,

explained how this takes place.[1] It appears that the copper wire covered with gutta percha, and immersed in water, or buried in the earth, produces a Leyden Jar arrangement upon the gigantic scale of upwards of 80 square feet internal coating, and 320 square feet external coating per mile:[2] the former being represented by the copper wire, and the latter by the film of moisture adhering to the outside of the gutta percha. Upon contact with the battery-pole, the copper wire becomes charged statically, with that electricity which the pole can supply,[3] and acts, through the gutta percha, by induction, (without which induction it cannot itself become charged,)[4] producing the contrary state of electricity in that film of water surrounding the gutta percha.

There being no outer coating to the suspended wires, (representing the earth, or the water in the case of a submerged wire,) these effects cannot take place. A slight momentary charge might, possibly, be detected upon a long, well insulated, suspended wire, owing to the fact of its being opposed throughout its distance to the surface of the earth; but from the distance between the inductric and inducteous surfaces, it would certainly be infinitesimally small.

A much more important difference exists, with regard to time, in the conducting powers of submerged and suspended wires. Professor Wheatstone, who was the first to measure the velocity of an electric current, stated, in 1834, that it travelled through a copper wire, suspended in a room, at the rate of 288,000 miles in a second. However, not only does the velocity of a wave of electricity vary through different conductors, but it has been demonstrated that, by various circumstances, such as altering the intensity of the current, &c., its velocity along the same wire may be made to differ. Thus, if the ends of a conducting wire be connected with the inside and the outside coatings of a Leyden battery, and be so employed to discharge a jar, it will be noticed, that the striking point will be considerably shorter than when the wire is used alone. This is caused by the tension of the electricity being lowered by the lateral induction. In the submerged wires, also, the induction consequent upon charge, lowers the intensity of the current, and consequently the discharge, or conduction, requires a longer time.

The following is a table of the measured velocities of electricity

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[1] *Vide* Lecture by Professor Faraday, "On Electric Induction—Associated Cases of Current and Static Effects," delivered at the Royal Institution on the 20th January, 1854.

[2] The copper wire is generally $\frac{1}{16}$th of an inch in diameter, and the whole covered wire gauges from $\frac{1}{32}$nds of an inch, to $\frac{1}{16}$ths of an inch.

[3] Davy: "Elementary Chemical Philosophy;" p. 154.

[4] *Vide* Faraday's "Experimental Researches," Art. 1177.

upon metallic conductors, given by several scientific men. It will be understood from what has been previously said, that notwithstanding the great difference in the results, it is perfectly possible, that the figures given for each experiment may be correct; the disparities being due to the difference of tension, or intensity of the current, occasioned by lateral induction, battery power, or, perhaps, to other causes.[1]

			Miles per Second.
Suspended wires.		Wheatstone; (1834,) copper wire	288,000
	[2]	Walker; (America,) iron telegraph wire	18,780
	[2]	O'Mitchell; ,, ,,	28,524
		Fizeau and Gonnelle; copper wire	112,680
		,, ,, iron wire	62,600
Submerged wires.	[3]	'A, B, G,' copper wire, London and Brussels telegraph	2,700
	[3]	,, ,, London and Edinburgh telegraph	7,600
		Clark, (1600 miles of subterraneous wire)	637
		,, 800 ,, ,,	754
		,, 400 ,, ,,	1,176

The wires experimented upon in the last case were eight in number, and each was about two hundred miles in length; they formed the underground line of telegraph between London and Manchester, belonging to the Electric Telegraph Company. It will be seen, that when the wires were looped together in couples at Manchester, a series of distances of four hundred, eight hundred, twelve hundred, and sixteen hundred miles could be combined in the London office. A galvanometer was placed at each junction of the several loops, so that the passage of an electric wave at that particular point might be noted. A similar galvanometer was also placed between the battery and the wire, or what is termed on short circuit. Upon establishing contact with the battery, the needle of the first instrument, (separated from it by only a few feet of wire,) was instantly deflected; after an appreciable space of time the second was affected; then the third; and so on, each in succession, to the last, distant sixteen hundred miles from the battery, in which the deflection took place about two seconds later than in the first. So long as the current was continued, a constant deflection was shown by all the galvanometers, varying according to the leakage upon the line. When the battery was disconnected, the first instrument immediately fell to zero, the others following in succession, but the farthest did not

[1] It is to be regretted, that there is no record of the battery power used in any of these experiments; though the latest researches seem to prove this to be of less consequence than was formerly supposed. Mr. Latimer Clark states, that he experimented with great care on one thousand miles of submerged wire, with different battery powers, varying from one to one hundred pairs of plates; and that he found the velocity of the current in every instance to be identical,—about one thousand miles per second.

[2] *Vide* Liebig and Kopp's Report: 1850.

[3] *Vide* Athenæum, January 14, 1854, p. 54.

resume its vertical position until upwards of four seconds after the first: thus showing a current flowing out at one end of the wire, while none was flowing in at the other end. It was found, that by a short connection of the battery, the passage of a wave could be traced along the wire, each needle, in turn, deflecting, and resuming its neutral position, before the succeeding one was influenced. Again, if after establishing contact with the battery, and then breaking it, the end was connected with the earth, a portion of the electricity in it rushed back again, and deflected the nearest needles in the reverse direction. This resulted from the wire discharging itself at both ends into the earth. In this manner also, by rapidly making and breaking the battery contact, and then connecting with the earth, a current could be sent along the wire through one, or more instruments, and then be recalled, before it reached the other coils; showing how signals may be sent by a perfectly insulated wire, which although good and legible at one end, never arrive at the other.

None of these effects, as to time, are visible upon a suspended wire of similar length, the signals in the first and last instruments appearing to be simultaneous. A theoretic, although inappreciable, period, does undoubtedly elapse, in the passage of a current, but it cannot be measured by the eye with the above apparatus, and no charge can be noticed.

In another experiment, made with the same wires, three of the galvanometers were replaced by steel points, and the current was made to pass through a strip of paper, soaked in ferro-prussiate of potassa, and thus to trace its passage in lines of prussian blue. A seconds clock also, connected with an independent battery, was arranged to make a dot upon the paper at every vibration of the pendulum. Four rows, or lines, of marks were thus produced, one under the other, the first representing seconds of time, and the others showing the presence of electricity at points upon the wire distant four hundred, eight hundred, and sixteen hundred miles respectively from the battery. A current was sent along the wire during five seconds. The result is shown in Fig. 1, which is an exact representation, on one quarter the longitudinal scale, of the record

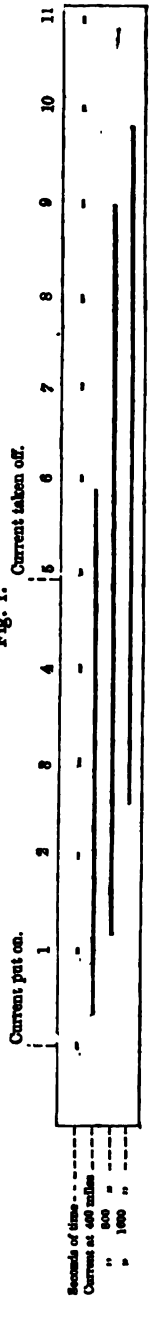


Fig. 1.

traced by the current itself in its passage along the wire.[1] That is to say, the current reached the

			Miles.	
400th mile in	0·34 sec.,	being at the rate of	1176	per second.
800th mile in	1·06 sec.,	,, ,,	754	,,
1600th mile in	2·51 sec.,	,, ,,	637	,,

and that the wire,

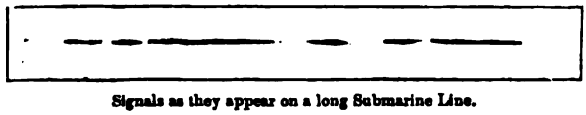
400 miles long,	discharged itself in	0·875	seconds.	
800	,, ,,	4·000	,,	
1600	,, ,,	4·500	,,	

This difference of velocity upon the same wire is due, as before stated, to the lateral induction. In the last-mentioned distance, (sixteen hundred miles), the Leyden arrangement was of the enormous extent of 130,000 square feet internal, and 520,000 square feet external coating; represented respectively by the surfaces of copper wire, and of the film of moisture surrounding the gutta percha.

The small difference observable in the time of discharge of the wire eight hundred miles in length, and that of sixteen hundred miles in length, is probably due to the fact, that the last eight hundred miles was not so well insulated as the first, and that, consequently, the current had an easier mode of escape into the earth.

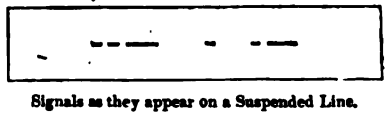
A current upon a long submerged wire, when recorded by the decomposing process, shows first, a mere point, which gradually increasing to a maximum thickness, remains unaltered until the battery is cut off, when it gradually diminishes to nothing. This proves, that power is consumed in exerting the lateral induction; then notifies the equal tension of the battery and induced currents, and finally shows the gradual discharge of the wire. Although a pretty and valuable experiment to the philosopher, this is a great obstruction in the working of telegraphs: what is sent as a dot, is produced at the other end of the line in the form of a double wedge (Figs. 2 and 3), and is liable to be mistaken for a line.

Fig. 2.



Signals as they appear on a long Submarine Line.

Fig. 3.



Signals as they appear on a Suspended Line.

[1] The original strip of paper, with the marks traced by the current upon it, was exhibited at the meeting.—Editor.

It will be observed, that the discharge invariably occupies a longer time than the charge; and since no subsequent signal can be made perceptible, until the wire is free, it follows that, in signalling, this time must be allowed to elapse between each wave and the next, deducting such lesser time as the following wave will require to reach its destination. In other words, the greatest speed, with which successive intermittent waves, in the same direction, can be received upon a submerged wire, is the time of discharge, less the time of charge, for a submerged wire of that particular length. For instance, from the above tables, intermittent signals along a submerged wire, could not be distinguished at a distance of eight hundred miles, unless a period of (discharge 4·00 seconds—charge 1·06 =) 2·94 seconds be allowed to intervene between each. In actual practice this speed is very considerably increased, by employing an instrument, first invented by the Author, and afterwards patented and improved by Mr. Cromwell Varley, which reverses the current with every signal sent, and so enables the wire to discharge itself quicker.

The difference in the working of electric telegraphs upon suspended and submarine wires, will now be evident. All electric telegraphs in actual use, depend for their signals upon a quick succession of waves. Some, such as Morse's, and Bain's, depend upon the number and their respective duration. Others, such as needle instruments, depend upon the number and their respective direction. Time, therefore, is an important element in all, though less so in needle instruments, than with others. There appears to be no practical limit to the speed of the transmission of intermittent waves, upon a suspended wire. The Author has seen a despatch transmitted by means of punched paper, and Bain's process, at the rate of six hundred and forty words per minute: and although this speed, or anything even approaching it, has never been attained for continuous public service, still, it is possible, and needs only some simple mechanical appliance to render it practically manageable. Upon submerged wires, on the other hand, as has been previously shown, the transmission is rigorously restricted as to time, according to the length of the line; and upon submarine and subterraneous wires, as at present constructed, a certain maximum of work only can be done, in a certain time; and by no mechanical contrivance at present known, can this limit be passed, so long as the condition of the wires remains unaltered.

It is very possible, that upon a submarine line between Ireland and America, one word with another, including the constant repetition of illegible signals that would be necessary, would occupy upwards of a minute in transmission, and consequently that each despatch of twenty-five words, with the code signals, would need

about half an hour:[1] thus making forty-eight despatches of twenty words each per diem, the limit for each wire.

It is not until a line is prolonged to six, or eight hundred miles, that the effects of the charge begin to be seriously inconvenient. Upon all the submarine lines in existence, it is very evident; but even upon the longest yet constructed, it is not sufficient to be of great annoyance. Messages are sent direct from London to the Hague, (a distance of two hundred and thirty miles, including one hundred and twenty miles of cable submerged in the Northern ocean, and twenty miles of subterranean wires beyond Ipswich,) at the usual rate of twenty words per minute.

It is probable, that the speed of transmitting intelligence upon long submarine lines, will be increased by the ingenuity and invention which characterise the present day; but it is evident, that there will always be some limit of possibility, so long as lateral induction can occur.

The Paper is illustrated by a series of Diagrams, from which the woodcuts Figs. 1, 2, and 3, are taken.

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[1] This calculation was based on the supposition that each complete signal would occupy 2·5 seconds in transmission; thus,—

For each letter, (average 4 signals,)	.	2·5×4, or 10 seconds.
,, each word, (average 6 letters,)	.	6×10, or 60 ,,
,, each despatch, (of 25 words,)	.	1×25, or 25 minutes.
,, code signals, repetitions of mistakes, &c.,		25+5, or 30 ,,

However, since writing the above, the Author has been informed, that it has been proved by experiment, that reverse currents may travel, like a wave, through a wire, one after another; so that the American wire *might* hold two, or more, complete signals in it at the same instant, and thus augment the speed of working twice, or thrice, as compared with the rate of any one given wave.—F. R. W.

Mr. WINDOW said, he had only referred, in the Paper, to the two kinds of submarine cables at present employed, — the simple cable, composed of one wire in each non-conducting envelope, a certain number of them being laid down side by side, so that in case of a casualty occurring to one wire the others might be made use of;—and the compound cable, wherein several wires were covered by one envelope of iron wire. He had alluded to the advantages offered by the simple cable, and this opinion, which was written some months back, had been confirmed by the recent casualties in the Channel. During the late gales, the Calais cable, which was of the compound kind, being torn asunder by the anchor of a vessel, there had ensued considerable inconvenience, until the transit of the messages could be arranged by another route; whereas the simple cables, although partially injured, had never ceased to be capable of conveying messages. He did not mean to say, that the simple cable would be the best for the connecting link between the west point of Ireland and the United States; but the case was worth consideration, at the outset of so important an undertaking. It had not been his object to disparage the attempt to convey telegraphic messages to America, nor did he mean to say, that the speed would be so slow as to be a bar to profit; but he had given his impressions, derived from experiment, chiefly with the view of eliciting information, from those who had better opportunities of investigating the subject.

Mr. CHARLES BRIGHT remarked, that some additions were necessary to render the Paper a complete report of the progress of submarine telegraphy up to the present time. The proportionate strength and weight of the different cables, and their construction; the depth and character of the bottom at the various sites, and the manner of paying out, as also some information as to the power used in the experiments recorded in the tables, should have been given. The proportions between the power of the current and the different lengths and kinds of wire should, likewise, have been examined.

The chief point suggested for discussion, was the difficulty of working, at such a rate as should be commercially successful, through such a length of cable as that now being constructed to connect Europe with America. There was reason to believe, that the effects of the phenomena of induction and retardation were exaggerated. The electrical conditions of an underground wire coincided with those of a submarine wire. It was true, that electric currents, employed in the usual way, with the common needle and recording instruments, were so retarded, that if worked quickly the signals were confused, or blended together; but this could be effectually dealt with.

The first important English underground line, coated with gutta

percha, was that laid by the Magnetic Company, in 1851, between Liverpool and Manchester. On connecting the wires at each end, so as to form a continuous length of above one hundred and forty miles, the effects of induction were clearly seen, and a strong secondary current issued from the wire, on breaking contact. But Mr. Henley's instruments met the difficulty, and promised, with some modifications, to overcome any extension of it likely to arise in the longer lines then contemplated. The novelty in these instruments was the mode of generating the current, its proportions as regarded intensity and duration, and in the method of acting on the needle. In the old plan a galvanic current was sent in one direction only, for each signal; the needle, or armature, being brought back to its place of rest by a weight, or spring. This, independently of the inductive effect, was objectionable, as that weight, or tension, had first to be surmounted by the current, and thus the power available to produce a signal was only the difference between the force of the current and the retaining power of the weight, or spring. In the system alluded to, the current was derived from a permanent magnet, and was (proportionately) more intense and rapid in its effect. The needle was equally poised on all sides, and worked as well horizontally as vertically. For each signal the needle was first deflected by a current in one direction, and then reversed by a current in the opposite direction, the currents being of precisely equal force and duration. This equality of time and force was a very important feature, for any difference was fatal to working through great lengths of wire affected by induction. In an instrument since contrived to work with reversed currents from a galvanic battery, in which the duration of the currents varied according as the signals, or pauses, were longer, or shorter, a short current was found not to be able to surmount the residual effects of a long one, and thus a proper neutralization did not take place. The increase of induction, by a current of great duration, was self-evident, and might be practically seen, by charging a well-insulated wire for some time; the return current, or discharge, had then more power than a brief current from the battery itself on short circuit.

On the completion of an underground line from London to Manchester, no cause for discouragement was found; as, with some alterations, the instruments worked admirably. Since then, the underground system had been extended, without any inconvenience as regarded electrical working. Indeed, instead of being limited, the longest circuits had been worked at the ordinary business rate, about twenty words a minute. Now, each letter, with the reversing system, required an average of four currents to be sent, and taking five letters to a word, there would be four hundred currents per minute, in practice; which would, from their length, only allow of

ten currents being sent in the same time, if the theory advanced was sound.

In considering the mode of working through still greater lengths, it was obvious, that the principle would require a different apparatus. In conjunction with Mr. Whitehouse, whose researches and ingenious instruments were so well known, he engaged in a series of experiments, which had produced most satisfactory results. Some of these experiments were repeated a few months back, for the satisfaction of Professor Morse, through two thousand miles of underground wire, connected so as to form a continuous circuit, terminating at both ends in the earth. Intermediate instruments were placed at each loop, to test the action of the electrical waves throughout the entire length, without any creeping of the current from wire to wire, and galvanometers were inserted at the distant ends. Signals were then clearly defined at the rate of ten to twelve words per minute. Two large induction coils,[1] three feet in length, excited by a powerful 'Grove' battery of fifty pint cells, but connected, for quantity, in sets of ten, were used to generate the currents. The power of working through very great lengths depended upon the force, duration, and proportions of the current used. From all that had been shown in the Paper, he contended, that no difficulty was likely to arise that could not be effectually dealtwith in working from Ireland to Newfoundland, by the proposed Atlantic cable.

Mr. T. R. CRAMPTON exhibited portions of the submarine cables, extending between Dover and Calais, and Dover and Ostend, which had been ruptured during the recent gales, by a vessel dragging her anchor, and hanging upon those cables consecutively. He stated, that although such force had been used as had ruptured the iron wire, and twisted it in a remarkable manner, yet the gutta percha covering of the copper wire was but little injured, and only exhibited a simple and clean section, all the rest of the covering being in as good a state as when it was first laid down, five years and a half previously. This was the first accident of the kind that had occurred, and it was immediately repaired.

Although his name had been prominently mentioned, in connection with the first successful and permanent application of submarine cables, he did not in any way claim the merit of the invention. The only improvement suggested by him was, that the external wires should be welded together, instead of being fastened by hoops. The merit that he did claim was, that when, at a par-

[1] The Induction Coil, stated by the Rev. Professor Callan to have been discovered by him in 1836, led to his devising, in 1837, an instrument for getting a rapid succession of electrical currents from the coil, and thus completing the coil, as a machine, by which a regular supply of electricity might be furnished.—EDITOR.

ticular juncture, the project for laying a cable from Dover to Calais was at a standstill, he took the matter up, at the instance of Messrs. Davis and Campbell, Solicitors, decided the course to be adopted, incurred the greatest risk, and carried it to a successful issue. He was, in fact, the first to realize an important project, whereby the world, by common consent, was materially benefited. No single individual, however, could execute a work of that kind in seven or eight weeks; and he had great pleasure in acknowledging the material assistance he received from Mr. Wollaston, an early labourer in the field;—and also from Messrs. Wilkins and Wetherly, who contracted for the manufacture of the cable, and designed in so short a time the machinery for constructing it. This machinery answered perfectly, although it was considered impracticable by Mr. Newall and Professor Gordon, who were supposed to be best acquainted with such matters. The manufacture of the cable was proceeding most satisfactorily, when, owing to circumstances to which it was unnecessary further to allude, it passed into the hands of Messrs. Newall and Co., by whom the same machinery and workmen were employed. The gutta-percha insulation was due to Mr. Statham, who so improved the machinery and the mode of manipulating that material, as to render it perfect for that purpose, after numerous unsuccessful attempts by others.

He was most anxious to bring forward the legitimate claims to priority of all those who had made investigations upon which the system was based, but, as had been observed in the Paper, the determination of such questions was attended with much difficulty, as inventions, or discoveries, of this nature, resulted from the combined investigations and experiments of many minds. He might observe, with regard to the submarine cable laid between Dover and Calais, that, although unknown to him at the time, and indeed for three years subsequently, its main features were shown in an elaborate and carefully executed drawing, prepared under the direction of Professor Wheatstone, in 1840. It was worthy of remark, that the arrangements therein indicated, agreed very nearly with those of the cables which were most favourably regarded at the present time; and although there were points which would have rendered it unequal to all the requirements of a submarine cable, yet in the hands of a practical man, such a drawing would have been quite sufficient, in his opinion, to lead to the desired result. The cable was proposed to contain seven wires, insulated by tarred yarn, the best means then known, and protected as at present, by a covering of iron wire. The drawing also gave a section of the English Channel, where the line was proposed to be placed, which was identical with that afterwards selected, and of the mode of manufacture of the cable itself. This drawing came

into Mr. Crampton's possession in 1854, and he was surprised to find, that so much attention had been bestowed upon the subject. There could not be any doubt of its authenticity, as it was known that Lutwiche, who made it, went abroad in 1841, and had not since been in this country. It was always said, that Lutwiche had aided Professor Wheatstone in working out the mechanical details of the proposed system of submarine telegraphs, stated by the Professor, before a Parliamentary Committee, to be practicable.

In the submarine operations upon the 'Royal George,' under Colonel (now Major-General Sir C. W.) Pasley, this system was also used to a certain extent, as well as by Dr. (now Sir W. Brooke) O'Shaughnessy, in India.

These facts did not, however, detract from the merit of Mr. John W. Brett, who agitated the question, and by his perseverance, kept it before the public from 1845 to 1850, (in the former of which years Mr. Jacob Brett obtained a concession from the French Government,) without, however, any successful result being arrived at. When the affair was nearly defunct, in consequence of the public refusing to subscribe to a scheme which was considered to be visionary, Messrs. Davis and Campbell, the Solicitors, having confidence in Mr. Crampton's representations, offered to provide one-fourth of the capital, if he would subscribe the same amount, and would undertake the direction of the enterprise. In his opinion, it was chiefly to the energy and confidence shown by these gentlemen, whose stake in the Company was afterwards largely increased, Mr. Crampton's shares being at the same time equal to one-half the capital, that the ultimate success was greatly due, and that the cable was laid in 1851. These facts should be recorded, to show the difficulty of commencing undertakings, which, when accomplished, were easily extended. He might mention, that Sir James Carmichael had also rendered most essential service, both by embarking capital in the undertaking and by his advice; as well as by the great exertions he used to obtain a second concession from the French Government, the first concession having lapsed; but in this he was not successful. It would be admitted by Mr. Brett that his attention had been chiefly devoted to other than the practical parts of the undertaking, which had been executed by others.

Mr. WINDOW observed, that the experiment relative to the velocity of electrical currents on submerged wires of four hundred, eight hundred, and sixteen hundred miles in length, made by Mr. Latimer Clark, and referred to in the Paper, formed the subject of a lecture at the Royal Institution, by Professor Faraday, on the 20th of January, 1854.[1] From this he had ascertained, that the

[1] *Vide* Lecture by Professor Faraday, "On Electric Induction—Associated Cases of Current and Static Effects," delivered at the Royal Institution on the 20th January, 1854.

battery employed was stated to consist of 360 pairs of plates (4 inches by 3 inches). Some misunderstanding appeared to exist with regard to an expression made use of in the Paper. It was nowhere stated, that by no appliance could any wire above a certain length be worked through, but that, although the difficulties of induction could be lessened, they could by no appliance be entirely avoided. Though allusion had been made to the fact of overcoming, to a certain extent, the effects of charge and discharge, due to induction, yet no description had been given in the Paper of the mechanical means by which these could be, and had been, diminished, because the technical explanations of such instruments were much more readily understood when given *vivâ voce*, and illustrated by the machines themselves. One of the first facts noticed was, the necessity for the employment of a battery giving electricity of a higher intensity than that used upon ordinary lines of the same length; this diminished sensibly the time of charging the wire, or the period that elapsed before the current arrived at its destination: but the discharge of the wire, which invariably occupied a longer time than the charge, remained unaltered. It must be remembered that, although lateral induction could be overcome by increasing the intensity of the current, according to the distance, yet this could not be carried beyond a certain point, for the electricity might have such an intensity as to destroy the gutta-percha covering, and so render the cable ineffective, a result which had taken place with a discharge from Rumkorf's coil. Many minor experiments were made, with more, or less success, to modify this effect. The magneto-electric telegraph seemed to be well suited for this purpose. It produced a current of great intensity, and the needle was returned to its normal position by means of a second current, of equal force and intensity, in the reverse direction, which had the effect of facilitating the discharge, or drawing off, as it were, the electricity accumulated in the wire. He had constructed an instrument calculated to perform the same office, by means of the galvanic battery. As the current thus produced could be made of equal intensity, combined with a greater quantity, than that of Mr. Henley's instrument, it was probably more suited for very long lines. A double-headed permanent magnet, that was, a needle having two north and two south poles, was suspended over the poles of an electro magnet, in such a manner, that it was deflected in one direction, or the other, according to the nature of the current. This instrument was used as a 'pecker,' to bring a local battery into action, the motion to the left making a contact, and that to the right breaking it. Signals were sent by means of a key, which upon being depressed, sent a current in one direction, and on being released sent another current in the other direction. These currents acting upon an electro-

magnet at the other end of the line, caused a needle to deflect to the right, or to the left, in the one case making contact with a local battery, and in the other breaking it. An instrument embracing this principle was now in universal use upon all the Electric and International Telegraph Company's lines, including the submarine wires to Holland and Ireland. It would be interesting to know, if the two thousand miles of wire upon which the signals had been sent at the rate of twelve words per minute, were extended in one single length, or whether they were composed of wires of the same cable, or inclosed in the same pipe under ground, and coupled up to that length. In the latter case a fallacious inference might probably be drawn from the result, as there would then be currents flowing in opposite directions, in immediate proximity to each other, and the induced currents would also be of an opposite nature, and thus neutralise each other. The effect of induction would, therefore, be very different to that upon a single insulated wire, of the same length, extended in a straight line.

Mr. BRIGHT remarked, that there was no such thing as two thousand miles of telegraph wire in one continuous length. In the experiment he had alluded to, ten separate lengths of underground wire, between London and Manchester, were connected together. As it was thought, that it might be inferred that the passage of the current was assisted by lateral induction, Professor Morse had tested this point very carefully, and had found, that the inductive effect from wire to wire was so slight, that a delicate galvanometer was not at all affected by it. It might, therefore, be fairly assumed, that no induction from wire to wire would affect the working of the instruments. He might mention, that, in conjunction with Mr. Whitehouse, he had tried some experiments on seven hundred miles of underground and submarine wires, in one direct length, from London, round by Scotland, to Dublin. This was the greatest length yet tried in a direct line, working to the earth, and in direct circuit with the wire,—and for that distance the results were most satisfactory. The coils used were about 12 inches in length. The coils employed in the experiment with the two thousand miles of connected wire were 36 inches in length, and were excited by a more powerful battery. Now, if they could work through seven hundred miles of direct wire, with the earth intervening, and could send an electric sensation through two thousand miles of connected wire, with four instruments in London, and four galvanometers in Manchester, he could not see what there was to prevent the working, successfully, through a direct line of two thousand miles. Professor Thomson, of Glasgow, was at one period a great opponent of the theory of the practicability of working through long distances, but he had seen reasons to change his opinion on the subject, and was now one of its warmest

supporters. The instrument which had been shown, so arranged as to send alternate galvanic currents by the motion of a finger-key, was defective in principle. There was this disadvantage in it, that instead of each current being of equal length, the first current to deflect the needle was of one length, and the second to bring back the needle was not always of the same length, so that the sensation through the wire was not perfect. For this reason, when working at the ordinary rate of transmission through a long submarine wire, the pause between a short signal and a long one would not be sufficient, to enable the short one to overcome the residual effect of the long one; when they charged a wire for a long signal, for, say $\frac{1}{10}$th or a $\frac{1}{4}$ of a second, a shorter signal would not be able to overcome it. It was a matter of duration, and of strength of the current.

The answer of the Author, with respect to the three-hundred and sixty cells, was not satisfactory, in an electric point of view. It did not appear, whether the intensity of the current had been increased, as the length of wire was increased from four hundred miles to eight hundred miles, and from eight hundred miles to sixteen hundred miles, or whether the same three hundred and sixty cells had been used in each case. Should the latter view be correct, as he imagined, then a different result could not have been expected, for the current would necessarily be slow.

The tables from which arguments had been extracted against the successful working of long lines of submarine wire showed, forcibly, the weakness of those arguments. It had been stated, that Professor Wheatstone proved the passage of an electric current to reach the enormous speed of two hundred and eighty-eight thousand miles per second, and the table gradually descended to only eighteen thousand miles, with other experiments on the same class of conductors. If the nature of the exciting powers had been recorded, the statement would have clearly demonstrated, that different proportions of power produced very different results. The first experiments were made with high tension electricity, the last with currents of greater quantity, and hence the difference. Reasoning from theory, without regard to practical results, taught that a very much greater rate than that named in the Paper would be attained in the line from Ireland to Newfoundland.

Professor William THOMSON (Glasgow) observed, through the SECRETARY, that the Author appeared to deduce from a theoretical investigation of the conduction of electricity, that it would not be possible to send more than one signal every seven seconds through the submarine wire proposed to be laid between Ireland and America. Now, Mr. Wildman Whitehouse had, in actual experiments, exhibited the transmission of distinct signals, at the rate of four per second, through a greater length of underground

wire than there would be required of submarine wire to connect Ireland with Newfoundland, for the United States line. He might remark, that in the Proceedings of the Royal Society (May, 1855),[1] and in the Report of the Proceedings of the British Association,[2] at Glasgow, in the same year, the theoretical objections now brought forward had been urged against the scheme, and satisfactory answers were given in the "Athenæum" of November 1, 1856,[3] and in a Paper read before the Royal Society in December, 1856,[4] all the reasonings being derived from actual experiment.

From these investigations it appeared, that without any direct trial on long subterranean, or submarine wires, but by reasoning on the known facts and measurements regarding electric conduction through copper, and electric induction across solid insulators, there were strong grounds for confidence, in expecting that a message of twenty words would not require more than seven minutes for its delivery, and that two hundred such messages could be sent during the day of twenty-four hours, through such a cable as was proposed to be laid across the Atlantic. There was even reason to think, that that rate might be ultimately exceeded, by the perfecting of the system introduced by Mr. Whitehouse.

Mr. LATIMER CLARK said, that he had not been able to find any record of the battery power used in the experiments quoted by Mr. Window. He had, however, records of similar experiments made with varying battery powers, which he had undertaken partly at the request of the Astronomer Royal, and partly for Professor Faraday, at the time they were determining the difference of longitude of the observatories of Brussels and Greenwich. These experiments were necessary, in order to ascertain what allowance should be made for the velocity of the currents, and whether it was essential for the batteries in England and in Brussels to be identical. He worked through a length of sixteen hundred miles of wire, commencing with a battery power of only thirty-one cells, increased by successive additions, up to sixteen times that power, or four hundred and ninety-six cells; and with each of these powers he took copies, upon Bain's paper, of the velocity with which the current travelled to the extreme end. He found no sensible variation in the velocity, which averaged about one thousand miles per second; though he soon ascertained, that there was no constant velocity. This depended upon many circumstances; to some extent upon the quantity of the battery

[1] *Vide* "Proceedings of the Royal Society," vol. vii., No. 13, pp. 382—399.
[2] *Vide* "Report of the Twenty-fifth Meeting of the British Association," Transactions of Sections, p. 21.
[3] *Vide* "The Athenæum" for 1856, p. 1338.
[4] *Vide* "Proceedings of the Royal Society," vol. viii., No. 24, pp. 299—307.

power, but more than all upon the thickness of the coating, the size of the copper wire, and the consequent amount of induction that was going on between it and the earth. Since then, Mr. Whitehouse had, in his presence, made experiments, through similar wires, first with the voltaic battery, and then with the current induced by an electro-magnet, and a difference in the velocity obtained by the two means was certainly indicated.

It might be imagined from the Paper, that no improvement had been made in the transmission of signals through submarine wires, and that the Electric Telegraph Company was still working at the slow speed described. This impression he wished to correct. The history of the affair was curious and brief. The difficulty of the induced currents was, he believed, first overcome by the Magnetic Telegraph Company, who employed Mr. Henley's machine for the purpose. It had been found, that although a current occupied a lengthened time in travelling to the end of the distant wire, and a still longer time to die out of the wire, yet if waves, or alternate currents, of positive and negative electricity, were sent, they would follow each other with considerable velocity. That was the principle used up to the present time, to obtain greater speed through underground and submarine wires. Mr. Henley's machine unwittingly did this, because at the time of its invention, underground wires were not extensively employed, and it was not designed with that intention. The next step originated with Mr. Window, who sent Mr. Clark the little instrument which he had described, and which he had been using for some kind of printing apparatus. Mr. Window thought that this machine, which acted on the principle of alternate reversed currents, by its sensibility and rapidity of movement, would overcome the difficulty appertaining to underground wires, and Mr. Clark was requested to try it. He referred it to his assistant, Mr. Cromwell Varley, to report upon. No report was however made; but some time after that, Mr. Varley took out a patent for a machine, in which the principal feature was the use of the reversed currents. He thought it important to observe, that although the crude idea of the use of alternate currents might have been derived from Mr. Window, still Mr. Varley had gone a stage further, and had introduced a variety of improvements, which had rendered his machine almost perfect.

Mr. Bright had alluded to a difficulty arising from the inequality of the currents. Now, Mr. Varley had invented a method, in which he commenced by sending a short, but very powerful current, resembling that of an induction coil, and ended by a current of much weaker intensity. By that means, all the advantages were obtained, as far as he could learn, of the induction coil. He believed the action of the voltaic battery could be made in all respects to resemble that of the current from the induction coil.

Mr. Varley's plan had this great advantage, particularly for overground lines, where there was an unavoidable escape of electricity from one wire to the others: that if an induced current was employed, in which a brief initial current only was sent, the machine, in the interim between two successive currents, was left passive, and was liable to be acted upon by accidental currents of a weaker character; but, by having a constant current, the magnet was not only moved to the proper side, but it was held there. When the current was reversed, the magnet was held in the opposite direction, and it was not likely to be affected by the weaker currents escaping from other wires.

The system of using alternate currents, or waves of positive and negative electricity, had enabled currents to be transmitted at a greatly increased speed. Professor Faraday had stated, that he had sent two, or three successive currents, of an alternately opposite character, into the wire, and after waiting an appreciable time, had received them at the other end. Mr. Clark was not able to confirm these experiments, although performed in his presence, but he had no doubt of their correctness. This system, of employing alternate currents, was the only one in use at the present time, to accelerate the working of underground and submarine wires, and he had no doubt that two, or three signals might be made to leave the hand of the operator, before the first had been indicated on a distant instrument.

Mr. CROMWELL VARLEY asserted, that his invention was prior to that of Mr. Window. His attention had long been attracted to the effects of induction in underground lines, perceptible indications of which he had noticed in the original subterranean wires through London, then insulated, in leaden tubes, by pitch and cotton. This fact he reported to Mr. W. H. Hatcher, the Chief Engineer of the Electric Telegraph Company, in 1848. He then used this induced charge as a severe test of the perfection of the insulation; the retention of it by the wire, for a short time after the battery contact had ceased, being a much more delicate test than that obtained by the galvanometers then in use for that purpose. From that time he had repeatedly tried experiments with subterranean circuits, and with wires suspended in the air from poles. In the year 1851-52, when it was contemplated to connect London with Manchester and Liverpool, by means of subterranean wires insulated with gutta percha, he inferred, from observing the large amount of induced charge in the London street wires, compared with those suspended in the air, that it would not be possible to work between those stations, with the proposed wires, at a commercial speed, with the printing instruments then in use. Mr. Varley brought this matter before the attention of Mr. George Wilson, the Chairman of the Committee

at Manchester, and he also mentioned it to the Engineer of the Company and to others. On the execution of the subterranean circuits these predictions were fully realised. Mr. Varley then considered how this difficulty might be obviated, and he invented a machine, which might be dated from October, 1853. This he had shown to the Secretary of the Electric Telegraph Company, but as he had not then obtained protection for it, for reasons which would be obvious, he kept it secret. It was whilst engaged in carrying out this design, that the 'relay' instrument of Mr. Window was put into his hands.

With reference to induction, and the speed of electricity through submarine wires, he believed that the electric current would travel through any length instantaneously. There was no appreciable time, between the application of electricity at the one extremity of a long conductor, and its appearance at the other end. The experiments of Professor Wheatstone and others proved that fact. Dr. Faraday's experiment with a suspended insulated globe and two insulated hemispheres, showed that the action of induction was only upon the surface, and that it was impossible to compress electricity into the body of a conductor. In all the experiments that Mr. Varley had made, there was no such thing as momentum, or inertia, evidenced by electricity. That being the case, it was only necessary to ascertain, whether a metallic conductor of very great resistance could entirely check the flow of the feeblest electric current. All experiments tended to show, no matter what the length, or resistance of the metal conductor, that it would conduct electricity through it, however feeble in energy, the quantity conducted being inversely in proportion to the resistance opposed to it. The lateral charge by induction was not a compression of electricity; it rested wholly on the surface of the gutta percha, or insulating covering, and was not in the substance of the wire.

In Professor Wheatstone's experiments, which indicated a velocity of 288,000 miles per second, the two wires were bent backwards and forwards, and were, therefore, under circumstances unfavourable to induction. But had the conductor been stretched out like a telegraph line, on poles, a slower speed would have resulted. This experiment, which showed that electricity occupied a longer time to pass across the intervals between the distant ends of the wires, than at the ends next the source of power, did not prove that electricity required time to travel along a conductor, but that the electric wave occupied an appreciable time in arriving at a sufficient intensity to leap over the interval. Had this separation in the centre of the circuit been increased, the speed would have been reduced.

The mistake, as to the non-instantaneous conduction of electricity,

had arisen from noticing only the arrival of the electric wave towards its maximum power, and not its commencement. The apparatus used being only capable of recording when the wave had reached a considerable intensity, the first and weaker portions of the wave were not observed. This explained the difference of the observed speeds of electricity from different sources, as also through conductors differently circumstanced. Electricity having neither momentum, nor inertia, being incompressible into a conductor, and being capable of travelling through any length of line, must begin to flow out at the one end, simultaneously with the application of the battery, at the other.

As a doubt had been thrown out, as to the existence of more than one wave in the wire at the same time, Mr. Varley would observe, that he had seen two distinct waves in a subterranean line eight hundred miles in length.

Mr. WILDMAN WHITEHOUSE, taking up the subject where Mr. Latimer Clark had left it, felt bound to acknowledge, that his researches had fully borne out the statement of Dr. Faraday, that different and distinct waves of electricity might co-exist in any long submarine conductor, at the same instant of time. In a wire of one thousand and twenty miles in length, he had distinctly heard three signals of a single-stroke bell after the hand had ceased to transmit signals: and, in like manner, in a length of four hundred and ninety-eight miles, two such signals in arrear had been distinctly heard.

In anticipation of the recently-proposed great extension of submarine lines, it had appeared to him desirable, that the laws affecting the transmission of electric signals in such conductors should be thoroughly understood. He had, therefore, endeavoured to work out some of the laws which governed these phenomena; inquiring whether the ratio of retardation was sensibly increased by increasing distances,—in other words, whether the tendency was towards an increase of retardation according to the square of the distance, or in accordance with the simple arithmetical ratio. Mr. Whitehouse, during the last two summers, had availed himself of the privilege of working out these problems, upon several cables which had been manufactured at Greenwich. Many of these results were obtained on a cable of one hundred and sixty-six miles in length. It had been made in two parts of eighty-three miles each, and each part contained three separate and perfectly insulated wires; thus giving a ready means of joining up six lengths in various ways, yet always having the ends under immediate observation. In this manner, currents were sent simultaneously, along parallel and contiguous wires, sometimes in similar, and sometimes in opposite directions, so that the effect of lateral induction, whether existing from wire to earth, or be-

tween wire and wire, might be ascertained. On another occasion the six lengths of eighty-three miles each were joined together, so as to form one total length of four hundred and ninety-eight miles. With this arrangement tests could be placed in each of the different loops of the long wire, so as, simultaneously, to note, at various distances, the progress of the current; making it record itself automatically, at its entrance at any of the eighty-three mile stages, and finally at the terminal station. He believed, that any attempt to make the currents record themselves by direct decomposition, as suggested by Mr. Latimer Clark, would be attended with inconvenience, and that with currents of low intensity, like many of those which he proposed to examine, it would be impracticable. These difficulties were obviated by the use of improved instruments, possessing these essential characteristics, that they were equally well fitted for purposes of philosophical inquiry, as for successful working in practical telegraphy. The receiving instrument, or 'relay,' was as sensitive as the best detectors hitherto used; so that a single cell, consisting of a piece of zinc and a piece of silver placed upon the tongue, sufficed to work through four hundred and ninety-eight miles and the earth, and had practically recorded signals upon a 'Morse' instrument. He inserted such 'relays' in the several junctions, or loops, of the cable, to note the rates of propagation, under various circumstances and conditions; so arranging them, with the use of a pendulum beating seconds, that upon the instant arrival of any current, a local battery should automatically print upon paper the time, in decimal parts of a second, which had been occupied in its transit. In this manner currents, not only too feeble to print by direct electro-chemical decomposition, but even weaker impulses, too feeble to be detected by ordinary galvanometers, were sent through considerable distances, and recorded practical results. Mr. Whitehouse had well considered the problem, as to what should fairly be deemed the first arrival of any given current, anticipating that theoretical objections might arise on this point. He thought that the first arrival of any current, up to the delicate standard of force alluded to, might fairly be termed the earliest practical arrival of the current for telegraphic purposes. With these means and appliances, he found, that the law of the squares, as hitherto held, was totally inapplicable to the phenomena in question, and that the tendency was to approach much more nearly to the simple arithmetical ratio. Having tried several thousands of experiments, under varying circumstances, he could now easily pre-arrange the conditions, and foresee the results. With an amount of electric force, inadequate as compared with the length of wire to be filled up, it was easy to see, that the retardation, occurring in the later portions of the transit, would follow a gradually augmenting ratio, in proportion to the increasingly

exhausted condition of the enfeebled current; whilst if the amount of electro-motive force was greater, and more fairly related to the length of wire to be excited, then a more uniform rate of propagation of the electric wave would obtain, in the several portions of any given length of wire.

Perhaps the most striking point in these researches, but still one in perfect harmony with all the rest, was, that with magneto-electric currents, he had obtained a rate of transmission two and a half to three times greater than that of any voltaic impulse he had tried. He produced automatic records, showing the comparative velocity of the voltaic and magneto-electric currents, tried under like conditions. There was this further advantage attending magneto-electric currents, that the wire could never be over-charged from an inequality in the due succession of positive and negative currents. This equal and alternate succession was indispensable, in order to obtain rapidity of signalling, as with a voltaic current, it would be almost impossible perfectly to equalize the amount of the successive opposite impulses.

As the subject of lateral induction between wire and wire had been introduced, he would state that this point had received minute and patient investigation. He had applied the severest tests, and had found that the results obtained would have been quite inappreciable, in all ordinary telegraphic operations. He had found a current, whose magnetic lifting power was 18,000 grains, when sent into a wire of one hundred and sixty-six miles in length, produced in an adjacent parallel wire, of equal length, a transient current of only $1\frac{1}{4}$ grains by lateral induction, or one in ten thousand, a proportion insignificant in amount, when compared with the full current under examination: and it was further proved by experiment, to exert no influence on the rate of propagation. In the further prosecution of this object, repeated experiments were made, with the view of comparing the results obtained, when the wires were used backwards and forwards, as in loops, with those obtained under other circumstances, when the current was made to enter the cable always from the same end, so that if in the former instance the wire always contained opposite currents, in the latter arrangement they would always convey like currents; yet, under no circumstances, could he find that induction from wire to wire in any way interfered with the rate of propagation of the electric impulse, or with any of the practical results. He, therefore, deemed it fair to conclude, that the experiments which had been tried with Professor Morse, and Mr. Bright, upon a length of two thousand miles of subterranean wires, connected together between Manchester and London, and worked through with test instruments, inserted at every loop, might be accepted as fully reliable, and free from any appreciable amount of error

due to induction from wire to wire; more especially as the results then obtained were in full and complete accordance with the conclusions legitimately deduced from previous experiments.

Sir CHARLES FOX stated that, in 1850, Mr. Henley called upon him, after having shown the magnetic telegraph instrument to some acknowledged authorities, by whom it was pronounced to be a pretty toy, but of no practical utility. Sir Charles Fox, however, happening to entertain a different opinion, took the instrument to Professor Faraday, who expressed the opinion, that it was the best telegraphic instrument he had seen, and that he believed the magnetic fluid would be found to be better than any other form of electricity for telegraphic purposes.

Mr. BIDDER, V.P., remarked, that it would have been desirable if some further information had been afforded, as to the means proposed to be adopted in laying the Atlantic cable; neither its construction, the materials to be employed, nor its strength, had been satisfactorily explained. Doubtless many contingencies would arise in carrying out this great undertaking—and it had not been stated how these were proposed to be overcome. The great depth at which the cable was to be laid would cause an unsupported length of upwards of two miles and a half to be presented to the action of currents, and to the shocks imparted during heavy seas. The strain upon the covering of iron wire would amount to 17 tons per square inch, and the compression of the gutta percha to $2\frac{1}{2}$ tons per square inch. It was just possible, that the strains so brought upon the cable might, in some degree, be taken off by the resistance of the water, and be partially expended throughout the whole unsupported length, and operate in straightening the curve it would assume; but, on the other hand, they might be more limited in their range, and then the question arose, whether the cable was sufficiently strong to meet these strains? It was true, that the Mediterranean cable had been laid at as great a depth, and was said to have failed only from a deficiency in the length; but, from whatever cause, it was a fact that that communication had not been made. Every one must feel a deep interest in the progress of an undertaking, which could not fail to exercise so important an influence on civilization and on commerce, and he would repeat the hope, that all would willingly contribute suggestions, which might have the effect of lessening the chances of failure, and of so insuring its probable success.

Mr. C. W. SIEMENS observed, that the subject under discussion involved two principal questions, which should be discussed separately, namely, the mechanical one of insulating, shielding, and submerging the metallic conductor, and the electrical question of transmitting messages through it when laid.

The first question had been treated by the Author of the Paper, and by most of the previous speakers, purely in a historical point of view; and some erroneous statements had been made, which it was important to correct. The non-conducting property of gutta percha was discovered, in 1846, by Mr. Werner Siemens, of Berlin. Being appointed a Member of a Royal Commission, charged with devising a plan for the establishment of Electric Telegraphs, in Prussia, he proposed, in the spring of 1847, the adoption of underground line wires, coated with gutta percha. In the autumn of the same year, he completed the first experimental line of twenty miles in length, between Gros Beren and Berlin, which was found to work successfully. Encouraged by this success, the Prussian and other German governments, adopted the underground system generally, and in the years 1848 and 1849, about three thousand miles were so laid. In March, 1848, Mr. Werner Siemens submerged in the Bay of Kiel several miles of copper wire,—coated with gutta percha by means of the cylinder machine, which he had invented in 1847,—for the purpose of establishing an electric communication between the shore and several points in the deep channel, where mines had been laid for warlike purposes; and this was undoubtedly the first attempt ever made to establish submarine communications.

In dealing with long underground line wires, Mr. Werner Siemens became acquainted with the lateral induction, or electric charge of the wire; and having fully investigated this interesting phenomenon, he devised means for counteracting its disturbing influence. In a former discussion at the Institution, upon a Paper by Mr. Window on "Electric Telegraphs,"[1] read in February 1852, Mr. Siemens fully described the working of the underground Electric Telegraph,[2] and the facts disclosed during that discussion tended powerfully to the introduction of that system into this country.

The question of the retardation of electric waves, in passing through long submarine cables, seemed still to be involved in mystery. Professor Thomson, in his Paper read at the meeting of the British Association in 1855,[3] enunciated the theory, that the retardation increased in proportion to the square of the length of the cable; whereas Mr. Whitehouse maintained, that the retardation increased only as the length, an opinion which he substantiated by the results of experiments. Now, Mr. Siemens contended, that Mr. Whitehouse's experiments did not disprove Professor Thomson's theory, but rather corroborated it, if all the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., pp. 299 to 329.
[2] Ibid., pp. 362 to 366.
[3] *Vide* "Report of the Twenty-fifth Meeting of the British Association," Transactions of Sections, p. 21.

circumstances of the experiments in question were taken into account. It had been supposed, that the increasing resistance in long conductors might be overcome by proportionately increasing the electro-motive force; but Nature had imposed its limits in this direction, for if the force became excessive, the discharge would no longer pass through the length of the cable, and back through the earth, but would cross the insulating medium in the form of a spark, and disable the entire cable. It had also been proposed, to send a considerable number of waves of positive and negative electricity simultaneously through the cable, but Mr. Siemens asserted, that the number of waves which could in that way pass through long cables, without destroying each other, was limited to three, or four. He did not believe that it would be possible to send through the projected Atlantic cable, more than one word per minute.

Mr. Siemens had carefully investigated this subject, and had, he thought, discovered means of accelerating the passage of an electric wave through a cable to twice its natural velocity, by simply returning the current through a second insulated wire within the cable, instead of through the earth. The two wires being simultaneously charged, the one with positive and the other with negative electricity, completely neutralized the electric charge of the metallic covering of the wire. Other disturbing causes, such as the magnetization of the surrounding iron covering, which exercised a very considerable retarding effect upon the electric wave, would also be removed. The positive and negative waves in the two enclosed wires, would likewise mutually accelerate each other, by voltaic induction. In the experiments of Mr. Whitehouse, the line wires had accidentally been under precisely similar circumstances to those provided by Mr. Siemens, but, judging from the projected Atlantic cable, it did not appear that the advantages obtained had been appreciated, as otherwise the cable would have been constructed on totally different principles.

Professor FARADAY, in stating his view of the cause of the difference in the velocity of the currents in different wires—which difference was in some cases as 1 to 100—would endeavour to avoid referring to his own theoretical views, because the facts stood apart from all theory. In sending a current, by means of a battery, one end of which was connected with the earth, through a gutta-percha-covered wire, to a point where it also was connected with the earth, a touch was given at one end of the voltaic battery, an impulse passed into the wire, travelled to the other end, gave its indication upon a magnetic indicator, and then passed away. If that was done with a wire suspended in the atmosphere, the current passed through almost instantaneously;

at all events the time was hardly appreciable, in a wire one hundred miles in length.

Now, if a Leyden apparatus, connected with the earth, but unconnected with the wire, was put into momentary communication with the voltaic battery, it would become charged. All experiments went to show, that the time occupied in the charging was very appreciable. The air wire alone transmitted the electricity it received from the voltaic battery very rapidly, but when connected with the Leyden battery, the electric impulse was occupied, in part, in raising up an induction in that apparatus, which was afterwards discharged through the wire; the discharge, and therefore the signal, being, however, retarded. When the wire, with its insulating covering, was made into a cable, or put into the earth, or water, it became itself a Leyden arrangement, the wire being one lining of the jar, while the iron, earth, or water was the other. The electricity then had to perform a double action, that of charging the arrangement, and that of sending on a current; the portion occupied in charging was for the time ineffective, as an advancing impulse, and though the charged part was at last discharged, at the place where the wire communicated with the signal apparatus and the earth, still time was required. In a long wire so circumstanced much time was consumed, and hence the inopportune effect which had to be overcome. Power, which should be exerted solely in advancing the impulse, was occupied, for the time, in a lateral inductive action. Whatever positive intensity of electricity, communicated by the battery, was occupied in inducing a negative state, on the conducting surface outside the gutta percha, that positive force was taken off from the propulsive energy which tended to send the charge forward in the wire. Whilst charging the near part of the wire-like jar, it was not occupied in pressing forward the wave; and the larger the jar, or the larger the wire, the more electricity was required to charge it, and the greater was the retardation of that electric impulse, which should be occupied in sending the charge forward. Even after the electricity had been sent in at the commencement of the line, and, that part having become charged, was discharging towards the further part, all the intervening parts had to be raised, in succession, more, or less, into the charged state. When the wire was suspended in the air, the lateral Leyden, or static induction, was almost insensible, and all the power of the electricity might be considered as occupied in driving the impulse forward; but when, as in the cable, it was surrounded by either iron, or water, or moist earth, much of the electric force was employed, for a time, in producing lateral charge, before it became current. Hence the cause of the great retardation, producing in some cases a difference in velocity of 100 to 1. These velocities, however,

were deduced from results with wires very differently circumstanced, and also of very different lengths: as regarded length, much had yet to be learnt by experiment. Professor Faraday was much interested by what Mr. Siemens had said, as to the results of voltaic induction, and also of magnetic induction, on the wire envelope. These must appear, though they would probably have to be considered as occurring at different moments, in different parts of a wire two thousand miles in length. He could state that, in his experiments, which had been limited to lengths of fifteen hundred and sixteen hundred miles between London and Manchester, with wires doubled up, and under the disadvantage of three, or four in one casing, he distinctly saw two waves at once, and he might perhaps have obtained three, or four. He was not aware what modification would take place, by working with one wire and one casing, compared with the working of several wires in conjunction; but his present expectation was, that the transmission of a signal along the proposed Atlantic cable would probably not occupy more than 2 seconds. That was his hope, from the data that had at present been obtained on the subject; but he had no practical knowledge of the result of an earth contact upon the anterior portion of the wire, or that part nearest to the battery, following a strong impulse charge, or its effect in clearing that part of the wire, and preparing it for a second impulse. With regard to the substitution of a negative charge for the earth contact, he should like to have some more definite results, before expressing any opinion as to the effect of throwing positive and negative charges into a wire of great length. He thought that the experiment of a transatlantic line was one which two such countries as England and America should glory in carrying out.

Mr. EDWARD HIGHTON observed, that the Paper before the meeting did not give any account of the losses, or failures, of several submarine electro-telegraphic cables, lately attempted to be laid down, from which more might be learnt than from a whole catalogue of successful operations. Neither had any mention been made of telegraphing through water, without wires, or any other metallic conductor.

The present successful submarine cables were a combination of a perfectly insulated wire, contained within exterior strong iron wires, running in a longitudinally spiral direction. He claimed the merit of the introduction of this kind of cable, and as corroborative evidence, referred to a judgment given in the Cour Impériale de Paris, when the Five Judges of that Court unanimously agreed in the opinion which had been expressed by the Attorney-General of France, that Mr. Highton was the actual inventor of the Submarine Metallic Conductor as now used. He

might add, that the present Solicitor-General for England also concurred in that opinion.

Although gutta percha, when buried in the earth, and acted upon under peculiar circumstances, was subject to decay, yet as far as past experience had gone, sea water seemed to be a preservative of that gum. He suggested, that the conducting wire of a subterranean, or submarine telegraph, might be protected from oxidation, or decay at any point of leakage, by means of an electric current.

No direct conclusion could be drawn from the table of velocities given by the Author of the Paper, in confirmation of which he referred to the following formula of Professor Ohm, for determining the velocity of the passage of a current of electricity:—

$$F = \frac{n E}{\frac{n D R}{S} + \frac{l r}{s}}$$

in which E was the electro-motive force; n the number of plates; D the distance of plates; R the specific resistance of fluid; s the section of wire; S the area of plates; l the length of circuit; and r the specific resistance of wire.

He then described the effects produced many years ago with two batteries, the one not exceeding the $\frac{1}{40}$th of a cubic inch, and the other the $\frac{1}{1000}$th part of a cubic inch; as also the application of Frictional, or Hydro-Electricity for telegraphic purposes.

The importance of a good system of code signals, where the cost of the intervening wire between two very distant stations was great, could not be overrated, and he exhibited a code by which an almost infinite number of signals could be transmitted with very few currents of electricity. He then described the method of sending messages simultaneously through the same intervening wire in each direction, without interference with each other; and he expressed the opinion, that if a thoroughly insulated wire could be laid and maintained between England and America, there could be no doubt that a much greater number of messages could be transmitted than had been predicted in the Paper.

Mr. BRIGHT, in reply to questions from different Members, said that the Atlantic cable was then in process of manufacture, partly at the works of Messrs. Glass, Elliot, and Co., at East Greenwich, and partly at Messrs. Newall's works, at Birkenhead. The best charcoal wire was used, and, as had been stated, to Mr. Brunel was due the credit of devising the kind of outer covering applied to the cable.

Mr. HEMANS said, although it might be a matter of minor importance, yet it was worthy of some consideration, whether the

spot selected for the home terminus of the cable, at Valentia, on the coast of Ireland, was the best that could have been chosen. It was fifty miles distant from the nearest railway station, and a lengthened overground telegraph would be necessary to complete the communication with London. He suggested Galway as a more appropriate spot for the terminus, as there was already a magnetic telegraph from that place to Dublin. The cable could be continued up the Bay to the Isles of Arran, free from danger of interference from the anchorage of vessels.

Mr. G. H. PHIPPS said, about seven years ago, he was engaged professionally to make a report upon the subject of an Oceanic magnetic telegraph. Although not then in possession of the information as to soundings, &c., which was now accessible, he arrived at the conclusion, that whenever the depth exceeded two miles and a half, extraordinary difficulties would be experienced in paying out the cable, whatever its circumference might be, so as to avoid rupture; because, after making an allowance of one-seventh of the weight, for the diminished weight of the cable in water, a depth of two miles and a half gave a strain of about 20 tons to the square inch. He understood, that the projectors of the present Atlantic line, considered that great additional strength would be given to their cable, by the use of fine wire for the strands surrounding the gutta percha; but in his opinion this would not afford a sufficient margin to meet the strain arising from currents and other contingencies, which must be taken into account, in addition to the strain upon the cable arising from its own weight. Any one who had had occasion to strain a rope of considerable length transversely in a river, with a current of two miles an hour, would be able to appreciate this remark, with regard to the force of the currents which would probably be encountered at sea upon two, or three miles of cable. The failure of the attempt to lay the line from Sardinia to the coast of Africa, showed the danger to be apprehended from any sudden check upon the cable. In that case the cable was paid out at a faster rate than the vessel progressed, so that although an allowance of fifteen miles had been made, the cable fell short, and they were obliged to let it slip. He did not think that the questions of the depth, and of the influence of the currents upon a long cable, had been sufficiently attended to.

Mr. CRAMPTON remarked, that several questions which had been asked in the course of the discussion had not yet been answered. First, as to the strength of the wire. He believed that the breaking strain would be about 3 tons, and, in his opinion, that was not sufficient to guard against the contingencies that might be expected to arise. With regard to the failure in the attempt to lay the Mediterranean cable, it was evident, that

when paying it out, the speed at which the vessel was going was not known; whereas the cable was really going out faster than the vessel was progressing; and they imagined, that by lessening the speed of the vessel, the tension upon the cable would be diminished; but by this proceeding the vessel lost her steerage-way, and got out of her course. The weight of the cable, and the depth at which it was being laid, tended to produce those results. Having given the subject a great deal of consideration he had arrived at the conclusion, that the proposed Atlantic cable should be made of such material as to afford the greatest strength with the least weight; taking care that the weight was sufficient to sink it rapidly. The iron wire covering adopted did not fulfil that condition. Now a cable could be made, of steel, of the weight of about one ton to the mile, of sufficient strength to meet almost any contingencies that might arise. Sudden changes in the weather were most to be feared in the laying of the cable. Recently, when repairing the Calais cable, one day they had fine weather, and the next day a gale came on which obliged them to run into Ramsgate.

He had hoped, that more definite opinions would have been expressed on the important question of the Atlantic Telegraph, and the silence which had been observed might lead to the belief of the proposed plan being generally approved by the profession. This, however, was not the fact. Contingencies should be prepared for, which was not the case with the present cable, and he must record his opinion, that the risk incurred was at least imprudent.

January 20 and 27, 1857.

I. K. BRUNEL, Vice-President,
in the Chair.

THE discussion upon the Paper, No. 952, "On Submarine Telegraphs," by Mr. F. R. WINDOW, occupied both evenings, to the exclusion of any other subject.

After the Meeting of January 27th, Messrs. Scheutz's Calculating Machine was exhibited in the Library, and was explained by Mr. Babbage and Mr. Gravatt, M. Inst. C.E. There was also shown a portion of a table of logarithms, which had been calculated, composed, and printed entirely by its aid, and without the use of types. It was estimated that these compound operations could be accomplished in less than half the time which a compositor would take to set the types; and at the same time all liability of error was avoided. The machine had been recently purchased by Mr. John F. Rathbone, of Albany, U.S., for presentation to the Dudley Observatory, U.S. America.

February 3, 1857.

G. P. BIDDER, Vice-President,
in the Chair.

The following Candidates were balloted for, and duly elected :— THOMAS FLETCHER CHAPPÉ, JOSIAH FORSTER FAIRBANK, HUGH EBRINGTON FORTESCUE, ROBERT WILFRID GRAHAM, WILLIAM WEALLENS, and THOMAS ALFRED YARROW, as Members ; COLONEL JOHN WILLIAM GORDON, R.E., C.B., MAJOR WILLIAM FRANCIS DRUMMOND JERVOIS, R.E., CAPTAIN CARLTON THOMAS COLLINGWOOD (Madras Artillery), WILLIAM BINNS, JOHN BRUNTON, EDWARD BYRNE, WILLIAM ROBSON COULTHARD, GEORGE DYSON, LÉON EPSTEIN, JOHN ENGLAND, JUN., HENRY CHARLES FORDE, CHARLES HENRY GRANT, WILLIAM BANCKS HALL, CHARLES EDWIN HEINKE, GEORGE KNIGHT, JOHN NEWTON, GEORGE ROBERTSON, BENJAMIN WARNES THURSTON, GEORGE THOMAS SELBY, and JOHN WITHERS, as Associates.

No. 947.—"The Varieties of Permanent Way, practically used, or tried, on Railways, up to the present Period."[1] By WILLIAM BRIDGES ADAMS.

IN the session of 1851-52, the Author presented to the Institution, a Paper "On the construction and duration of the Permanent Way of Railways in Europe."[2] Several of his views were then strongly contested, but as some time has elapsed since that discussion took place, he is now induced to return to the subject, with an increase of practical experience.

If, as is generally acknowledged, the "Permanent Way" of railways is, for the most part, anything but permanent, it must not be forgotten, that it has ceased to be sufficiently permanent, chiefly because the locomotive engines, now used, are double the weight of those for which the original lines were designed. The calculations of Engineers have been baffled by the increase of traffic, and the proportion of the strength of the road to the weight of the engines has to be settled anew.

It is advisable then, in the first place, to determine what are the mechanical principles essential to the efficient construction of Permanent Way. The first principle to be attained is non-deflection,

[1] The discussion upon this, and the subsequent Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

[2] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., pp. 244 to 273.

either vertically, or laterally,—not absolute non-deflection, but so much stiffness in the rail itself, as will distribute the pressure equally over a considerable space, so as not to crush, or disturb the ballast, or bearing surface, with a constant short wave of rail rising in front of the engine-wheels, by the yielding of the ballast beneath the weight. In proportion as the rail is strengthened, or the engine is lightened, so will be the perfection of the road, and the greater will be the proportion of duty obtained from the locomotive.

The second principle must be, such an arrangement of the joints of the rails, as, while permitting expansion and contraction in each length of rail, will preserve, as nearly as possible, equal strength of resistance over the whole surface. For though the theory of a continuous bar without joints, may be practically borne out, in peculiar portions of a line, still, rails, for various practical reasons of manipulation, must continue to be in lengths, with joints between the lengths. If the joints be weaker than the intermediate portions, the diminishing resistance will approximate to the condition of a blow, and *vice versâ*, if they be stronger. It would be better to have a rail of too much deflection, provided it was of equal strength throughout, than to have a non-deflecting rail, with weak joints.

The third principle is to have the surface of the rails so constructed, as to prevent any mechanical change, such as laminating, or crushing, from rapidly taking place by the action of the wheels rolling over them. This may be accomplished in two ways, either by condensing, or hardening the surface, or by widening the rails and increasing the amount of bearing; in both cases the surface must be equally hard, or equally wide throughout. A soft interval in a hard surface, will be equivalent to blows destroying the rail; and such would be the case, also, if the irregular tilting of the rails laterally, were to cause a variation in the tread of the wheels.

The fourth principle is, that the rails must have such an amount of bearing surface below them, either by their own structure, or by the intervention of sleepers of sufficient area, as to prevent their crushing into the ballast, or ground on which they may be laid. At the same time, it must be borne in mind, that the surface of the rail itself must be sufficient, either by its own width, or by some artificial extension of its width, such, for example, as chairs supply, to prevent it from crushing the sleepers. The attachment to the chair and sleeper should be of such a kind, as to permit of no loose movement, which might induce hammering and destruction.

The fifth principle is, as far as possible, to use only such materials in the construction of the way, as, while mechanically strong enough, or rather with some surplus amount of mechanical

strength, will also be effectively durable. The perception of this, no doubt, led the late Mr. George Stephenson to use stone blocks for sleepers, and the principle was sound, and had not the hurry of making Railways prevented the thorough working out of the details, they might probably have been continued in use.

The sixth and last principle is, the medium on which the way is to be laid. On solid ground, porous ballast is preferred,—in order to drain away moisture. In boggy ground, a floating medium is required, and the tanning property of bog-water renders wood of any kind a very durable material, as it prevents its chemical destruction.

Many varieties of Permanent Way may be made to comply with these principles, and in choosing between them, the consideration should be, which of them can, with equal efficiency and durability, be made to combine the greatest simplicity with the smallest cost, both in outlay and in maintenance.

Reasoning on the foregoing principles, it is obvious, that the deeper the rail can be made, the greater will be its vertical strength to resist deflection. But the mode of its application may involve much difference in cost. If the rail be insistent, or supported on its base, the vertical web must be sufficiently stiff, to prevent it from buckling under the downward pressure; and the breadth of the lower web, or foot, or of the chair, must be increased in proportion to the height. An ordinary bridge rail is 6 inches in width and 3½ inches in height; the horizontal base being as twelve to seven of vertical elevation. It is obvious, that the closer the tread surface of the rail is to the bearing surface on the ballast, the less will be the tendency to rocking, or oscillation; and how this arrangement may best be reconciled, with such a depth of rail as will prevent deflection, is a problem which it is desirable to solve.

Beginning chronologically, it will be remembered, that the earliest rails were merely wooden planks, laid on the "way leaves" in the North of England. As these planks wore away, they were replaced with iron bars. Cast-iron tramways succeeded, and they were, in time, replaced by wrought-iron tramways. The great revolution was, removing the guiding flange from the rail and placing it on the wheel, and using what was early called the "edge-rail." By this plan, dirt, or obstructions, are not liable to collect in the path of the wheels, the tread of the wheels being elevated above the bearing surface.

The rail assumed, at once, the most obvious form, that of a T bar, with the vertical portion deep enough to bear the insistent load, and the horizontal portion an inch and three-quarters in width, which was considered sufficient to serve for lateral stiffness, and for the tread of the wheels. This form of rail neces-

sitated the use of chairs to support it, and these were made of cast iron.

Two other classes of rails were subsequently adopted, apparently with a view to get rid of chairs; the foot, or contractor's rail, and the bridge rail. The first is, owing to the difficulty of rolling, only made about 4 inches wide at the base, and this could not be increased without very wastefully thickening the iron at the foot. The height was usually about 3 inches, but latterly it has been increased to 4 inches, and upwards.[1] Thus the height is, in many cases, greater than the base, and it should, therefore, be used with appliances to widen the base. Used as it is in America, by merely spiking down with dogs on the edges upon fir sleepers, it can only be a source of constant repairs. The bridge rail, in the process of manufacture, offers facilities for widening the base to any desired extent, and also for giving any height required. But, as it is composed of two vertical webs, the weight is very materially increased, as compared with other rails. A bridge rail 5 inches in height, with a base of 8 inches, would weigh about 100 lbs. per yard.

The next in order is the double I rail, which, from the period of its first introduction by Mr. Locke, V.P., has been more largely used than any other. One advantage it possesses, is its facility of being reversed. In ordinary practice, the process of reversing is commonly adopted for crushed, or flawed rather than worn rails, as the latter will not fit in the chair when reversed. It is advisable to point out how this occurs, for the popularity of this rail has led to numerous attempts to improve the mode of fastening. The sectional form of the rail imperatively demands an artificial base. The ordinary chair supplies this. The apparent reason for the peculiar form of the chair, is the facility of removing and replacing the rails, by driving out the keys, without disturbing either the chair or the sleeper, of which the chair is supposed to become a part. The 'tables' of the rail form a double parabola, and generally not more than two inches, and sometimes less, of the bottom table bears upon the chair, and then it rests on a slope, to which it is confined by the wood key, or, as a variation, by iron keys. The lateral blows of the wheels continually compress the keys, the rail becomes unsteady, springing up and down, and laterally, as may be detected by the noise, and as is proved by the channels cut across the rails and across the chair seats. This effect is more conspicuous since the increase in the weight of the engines; but the process was always in operation. Wherever a blow exists, it indicates a deficiency of adjustment, and moisture causes rust, which is rubbed off and renewed, till, partly mechanically and partly chemically,

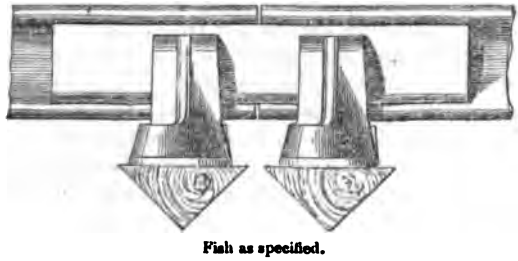
[1] Since this was written, this class of rail has been manufactured with a considerably extended height and base.—W. B. A.

the rail becomes useless. There is another disadvantage in the use of the chair. The seat, or bottom, cannot, with certainty, be less than 2 inches in thickness,—and as the depth of the rail is 5 inches, this makes a total of 7 inches, or adding the thickness of the sleeper, a total elevation of about 12 inches above the bearing on the ballast. A chair of 10½ inches to 11 inches in length is necessary to hold firmly to the sleeper. The raising of the rail so high, gives a mischievous leverage to the lateral blows of the wheels, and tends to spring the sleepers, and disturb them in the ballast. Of course, so long as the rail and chair are firmly fixed together by these fastenings no blows take place.[1]

Up to the year 1847, but few attempts had been made to improve the joints of the rails. On the Blackwall Railway, a vertical scarf joint had been effectively used to obtain a continuous surface, before locomotives were employed on it; and Professor L. D. B. Gordon subsequently tried a horizontal lap on the Eastern Counties Railway. But, in both cases, entire dependence was placed on the chairs and sleepers, to keep the rails in position; as the rails were not formed into continuous bars, independently of the sleepers.

In that year, the double I rails in use on the Eastern Counties Railway were found to be so frequently damaged at the ends, by the rolling of the wheels above, and the hammering in the chairs below, that it was impracticable, any longer, to keep them firm. To remedy this evil, the Author specified the plan of removing the joint chair and sleeper three inches back from the joint, and applying another chair and sleeper three inches on the other side of the joint. An iron 'fish,' resting in, and supported by the two chairs, was then placed in each rail channel, so that the joint became, as it were, suspended (Fig. 1). This had

Fig. 1.

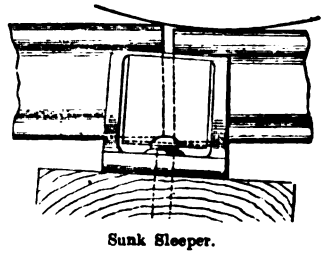


Fish as specified.

[1] In the United States, the battering of the ends of the rails in the chairs is so excessive, that an india-rubber bearing is said to have been adopted with great advantage. A continuous bearing of cork has also been laid experimentally, for upwards of two years, under bridge rails, on one of the metropolitan lines, to prevent vibration on girder bridges.—W. B. A.

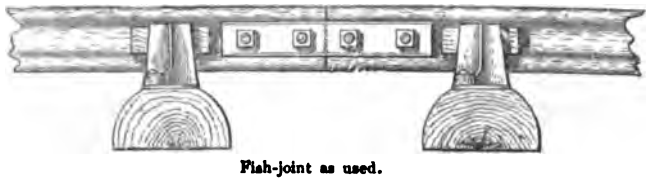
the effect of converting each rail into "a beam fixed at the two ends," which was not the case with an ordinary joint chair, in which the wear of the wood key leaves the rails loose, so that the end of each rail springs up before the wheel arrives, and is beaten down when the wheel passes over the joint (Fig. 2). The desire to avoid casting fresh chairs, for the additional number required by the 'fishing' process, led to removing the chairs to 20, or more, inches apart, and to bolting the fishes to and through the rails, by four bolts (Fig. 3). In some cases the fishes were applied, by simply removing the joint sleeper, leaving a distance

Fig. 2.



Sunk Sleeper.

Fig. 3.



Fish-joint as used.

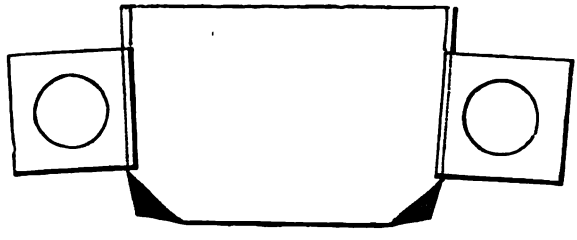
of from 3 feet to 4 feet, between the other sleepers, unsupported, the result of which was the breakage of the bolts. The chief defect of the double I rails under the modern heavy engine,—want of lateral stiffness,—is aggravated by this arrangement.

There is no doubt, that a good firm joint can be made, with the chairs 20 inches apart, by bolting the fishes to the rails, so long as the fishes fit, and the bolts are kept tight. But it is obvious, the form of the rail channels is not that best adapted to keep the fishes firm. The inside angle of the tables of the rail is about 45°; and, consequently, the fishes can only be retained by the end tension of the bolts. The joint being suspended, the vibration of the trains is not absorbed by the sleeper, and the nuts are gradually jarred loose. When this takes place, the rails wedge themselves in between the fishes, and a very short period of neglect, so damages both rails and fishes, as to render it impossible to keep them tight. To remedy this evil, various plans have been tried. One, by the late Mr. C. H. Wild, is to roll a groove in the fish, to prevent the bolt-head from turning. A second, by Mr. W. Pole, (M. Inst. C. E.,) is to tap the screws of the bolts into one of the fishes. Another plan is to use double nuts. There is no doubt, that the fish joints wear out, and are not absolutely permanent. This is due to the section not being deep enough vertically, so that the

fishes are apt to bend and set, and to their not fitting closely in square-cornered channels of the rails. But, with rails used in the ordinary mode, this would not be practicable, for unless the corner be well rounded, the table would break off. This difficulty has been experienced in other countries as well as in England. Mr. Bullard, an engineer of railways, Boston, U. S., writes to the Author: "Our roads have experimented with the common rolled plates for some years, but they do not prove of utility, and in many instances have been abandoned."[1]

The difficulty of keeping the bolts of ordinary fishes tight has been found to be so serious an evil, that the Author was led to devise a simple plan of keying them (Fig. 4). The bolt-heads and

Fig. 4.



Lock-bolts for Fishes, or Brackets, or other Rail Fastenings.

nuts have edges bevelled to an angle of 45°, where they press against the fish plates, so that they form a kind of groove, when the bolts are screwed tight. A thin wedge plate, with a bevelled edge, is driven into the grooves, between each pair of nuts, and if the nut is not screwed quite tight, the wedging action will tighten it. The lower corners of the wedge being bent upwards, it is fast, and the bolts cannot get loose, unless by becoming lengthened, by the rails opening the wedge angle of the fishes.

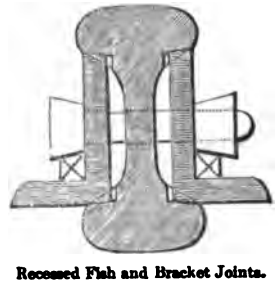
The want of fit between the fishes and the rails, led the Author to suggest that the channels of the rails, wherein the fishes abut, should be made of a square form, by pressing them between dies whilst hot. Two, or any other number of punches may be inserted

[1] Since this was written, the Author has examined many fishes which were purposely taken up by the engineer on one of the metropolitan lines. They presented the appearance of a bar bent downwards in the centre, and were, practically, bent bars, though the bending was produced by attrition. On the upper and lower edges, a projecting cross-rib was left between the ends of the rails, indicating the original level of the metal, and an indentation was made in the rails, on the lower side, at the ends of the fishes. This result was produced by the injudicious practice of suspending the rail joints between distant supports. The object of the Author, in originally suspending the joint between the chairs, was to obtain a firm bearing,—not to be obtained in the battered rail ends of existing lines,—the distance being then only six inches between the chairs.—W. B. A.

in the upper die, so that when, by pressure, or by blows, the dies are forced together, the side channels will be squared for the length of the fish, and the bolt-holes be punched at the same time. The squeezing of the metal from the inner sides of the tables of the rails, will condense the material of the ends advantageously, as well as make an accurate joint for the fishes. When the rail leaves the rolls, one end may be at once cut off and pressed; the rail may then be allowed to cool, and afterwards the other end may be heated and pressed, by this means the lengths of the rails will be more accurate; or, the rails may be cut as usual, and the ends be stamped and punched, one after the other.

The improved fishes to be used with the rails thus prepared, are rolled with a projecting rib at the bottom edge, and are made to fit the rail, with a very slight wedging action (Fig. 5). The bolt-heads and nuts are slightly pyramidal, and of such a size, that they can just turn round clear of the rib. Keys are driven in between the bolt-heads and the nuts and the rib, so that the bolts cannot work loose. Moreover, on account of the squared channels, there will not be any wedging strains on the bolts, and the additional breadth, due to the ribs, will afford increased lateral strength, as compared with the ordinary fish. An improvement on this plan, is to use a rail prepared in the same manner, with wrought-iron brackets, and bevilled bolts and nuts, keyed below, dispensing with the two joint chairs and fastenings, required when fishes are used.

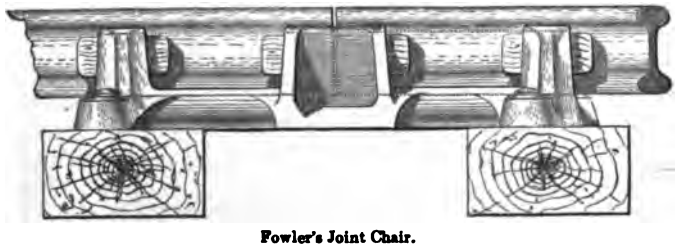
Fig. 5.



Recessed Fish and Bracket Joints.

The next class of joint practically used, is that introduced by Mr. John Fowler, (M. Inst. C. E.,) on the Manchester, Sheffield, and Lincolnshire Railway, in 1849 (Fig. 6). This was a large

Fig. 6.



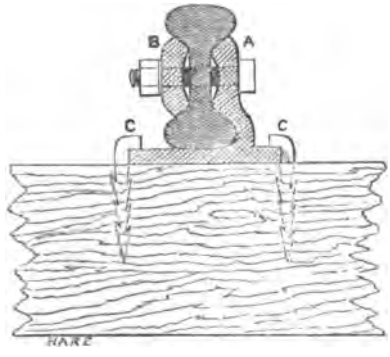
Fowler's Joint Chair.

casting, 2 feet 6 inches in length, being practically three chairs cast

together, and resting on two sleepers, the rails being confined by three ordinary wooden keys. The great length of bearing was no doubt advantageous, in saving the lower table of the rail from damage; but if the timber is not sufficiently firm to prevent the rails from springing, the rails cannot come under the category of "beams fixed at the ends."

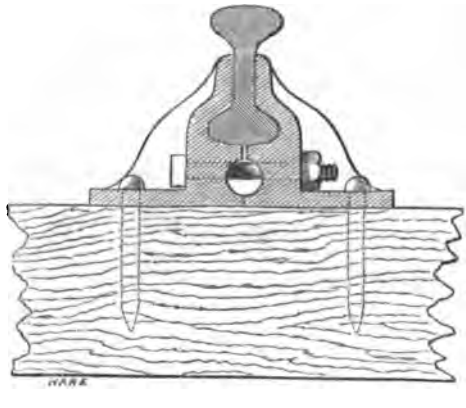
In the year 1850, Mr. James Samuel, (M. Inst. C. E.,) produced his fish chair, which is a combination of a chair, with one jaw elongated, and of a fish of wrought iron, bolted together, to and through the rails (Fig. 7). The object of this fish chair was to save the expense of laying down another sleeper with its chairs. This plan involves a mechanical difficulty. To make castings to fit the surfaces of the channels of the rails, against the top and bottom web, and below the bottom web, is scarcely practicable; the more especially, when it is recollected that rails constantly vary in their section, by the wear of the rolls.

Fig. 7.



About the same period, June 1849, Mr. Peter W. Barlow, (M. Inst. C. E.,) produced a chair in two halves, bolted beneath the rails (Fig. 8). This was not subject to the defect of

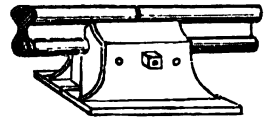
Fig. 8.



Mr. Samuel's one-jawed chair, inasmuch as it took no bearing on

the upper portion of the rail, but merely clipped the lower table. The great height of this rail above the sleeper, and the leverage of the rail on the two half chairs, have a tendency to loosen them; and for this reason, it would appear, that their use has been rather experimental than practical, the fish joint being used in preference on the Midland Railway. In this arrangement, Mr. Barlow had been anticipated by a Mr. John Day, as early as January 1835. Fig. 9 is taken from a lithograph entitled "John Day's Patent Cast-Iron Base Plates for Railways." These base plates were proposed to be used as chairs, in two parts, and to be bolted down on wooden sleepers; the bolts passing through the two half chairs below the rails, as in Mr. Barlow's plan.

Fig. 9.



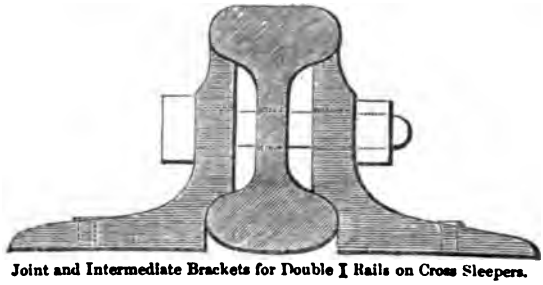
Day's Cast-Iron Base Plates.

In 1852, Mr. Mansel produced, on the South Eastern Railway, a peculiar kind of joint, of combined wood and iron. Short pieces of half balks of timber were grooved along their upper edges, the grain being vertical, and the grooves were brought together so as to form one groove. Two fishes were laid in the channels of the rails, and, when so prepared, the rails and the fishes were laid in the grooves. The timber was then clipped to and through the rails, by bars and cross bars with keys, and all was packed in the ballast together, forming practically, a split pile a foot in depth. A considerable number of these were laid down by Mr. T. Drane, (M. Inst. C. E.); but it is said, they have since been removed by a succeeding Engineer, and have been replaced by fish joints of the ordinary kind. This joint is shown in Plate 2, Figs. 2 and 11.

In the same year, Mr. McConnochie produced a new kind of chair, cast in two parts; one part being a cast wedge, sliding in with the rail, so that downward pressure kept it tight, while the upward rising was prevented by a wood key. This system, therefore, did not fulfil the condition of "a beam fixed at the ends," as the springing of the rail tended to crush and loosen the keys. These chairs were applied on the Liverpool and Southport Line.

In February 1853, the Author, after careful observation of the whole system of joints, and their advantages and defects, arrived at the conclusion, that the best mode of securing the double I rails to the sleepers, whether joint, or intermediate, was on the principle of the bracket, or ship's knee (Fig. 10, p. 236). The fish and the chair are abandoned altogether, and the rail is fixed on, or in, or slightly above, the sleeper, so as to be wedged below if preferred. The rail is secured in position by the application of knees, or brackets, bolted to and through the rails, and to the sleeper also, precisely as a deck beam is fastened to the side framing of a ship. That this was thought a good system may be assumed from

Fig. 10.

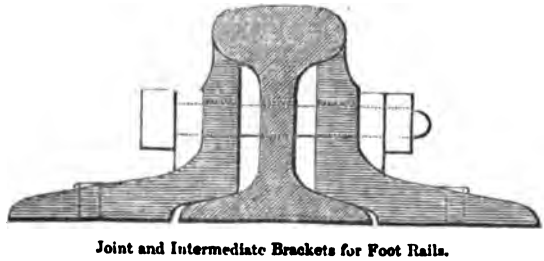


Joint and Intermediate Brackets for Double I Rails on Cross Sleepers.

the fact that Mr. C. H. Wild specified it one month after the Author, and Mr. Liddell twelve months later. It is now in use on the Great Northern, the South Western, the Western of France, and other lines, and is preferred to the fish joint, as it appears to be more durable, the bolts are less likely to be loosened, and the saving of outlay in repairing an old line amounts to about £150 per mile. This arrangement fulfils the conditions, of keeping the rail as low as possible on the sleeper,—2 inches lower than the chair system,—and of saving the lower table from damage by blows, while the worn top does not interfere with its being firmly fixed when reversed, so that it is really a reversible rail. There are no keys to get loose, and the bolts are saved from much vibration, by the structure being bedded on the timber. The joint brackets are 1 foot 6 inches in length, with four bolts, and weigh from 42 lbs. to 45 lbs. per pair. The intermediate brackets are 4 inches long, with one bolt, and weigh 11 lbs. per pair. The rails thus become "beams fixed at the ends." None of these brackets have broken on the Great Northern Railway, where tre-nails are used. Five have broken on the South Western Line, all exactly through the strongest part, in a line with the spike hole, evidently from too tight a fit of the spikes, which burst them just as a stone is broken by wedges.

These brackets can also be applied to the foot rail (Fig. 11),

Fig. 11.

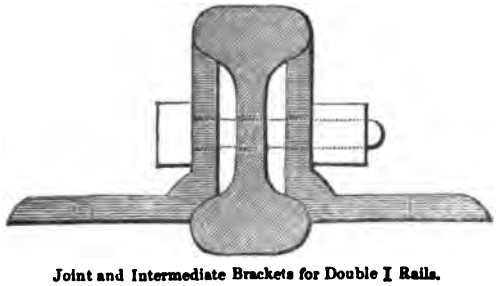


Joint and Intermediate Brackets for Foot Rails.

and when so used, form an extended base to the rails, preventing any rocking movement, by the side lurches of the wheels. With a single pair of intermediates in the centre of each rail, in addition to the joints, the whole will be kept very firm. They involve less cost than any other efficient method. Some of these brackets, both joints and intermediates, were laid down on the South Western Railway, near Kingston, in June 1855, and at Putney in September of the same year. They have given such entire satisfaction, that a further quantity is being laid down on the metropolitan extension of that line. Some have been made with the bearing surface extended in a thin web below the rails without touching them; but this method has the disadvantage of increasing the elevation of the rail, exposing it to leverage, and also increasing the quantity of the metal; though it tends to prevent the brackets from tilting inwards, if the bolts get loose. Should, however, the bolts get loose, the rails may drop down, and break away the central portion.[1]

In some cases the lower table of the rail has been grooved into the sleeper, by which the gauge and pitch of the rail is accurately secured, and all strain by the lateral blows of the wheel is removed from the holding-down spikes (Fig. 12).

Fig. 12.

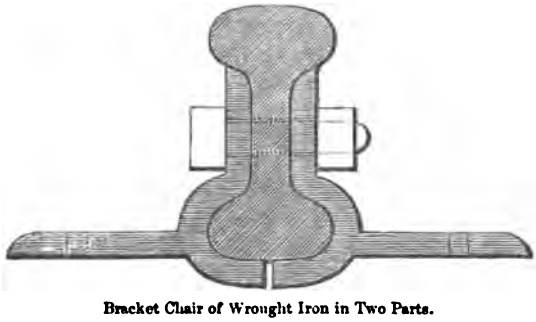


Joint and Intermediate Brackets for Double I Rails.

[1] A considerable number of these brackets, rolled in wrought iron, with an under lip below the rail, have been applied on the South Western Line, and with good effect. They are 15 inches in length, have four bolts, and weigh 42 lbs. per pair. They are made to fit the side channels of the rails accurately, between the upper and lower tables, and if any wear takes place, the rails will rest on the under lips. But in reversing the rails, it will be necessary to chip their edges, if they happen to be spread out in wear, and then they will not rest on the under lips, on account of the reduced surface. Cast brackets are to be used on the Direct Central Railway, and wrought-iron brackets applied to the joints of foot rails have been recommended for the Grand Trunk Railway of Canada. The Engineer of the North London is also adopting cast brackets for the joints of the Double I rails, and on the Great Northern, after two years' experience of thirty miles as laid, an additional length of sixty-seven miles is shortly to be laid. In examining cast-iron brackets which had been some time in use, loose bolts were found; but the rail joints were well preserved, by the inward pressure of the upper lips of the brackets beneath the rail table owing to their leverage on the sleeper. Key bolts, instead of screw bolts, may be used with the brackets if preferred.—W. B. A.

In other instances, a bracket chair, of wrought iron, in two parts bolted through the rail, to which it is closely fitted, and supporting the upper table, with the lower part recessed into the sleeper, has been used. These bracket chairs may be made of cast iron, but it is difficult to obtain an accurate fit of all the parts (Fig. 13).

Fig. 13.



Bracket Chair of Wrought Iron in Two Parts.

In February 1854, Mr. W. H. Barlow (M. Inst. C.E.) produced a new variety of joint chair, specified as a double wedge. It was a long chair, and instead of the ordinary wood key, two cast keys were drawn in close to the rail, along an inclined plane of the chair jaw, by a long bolt passing through the centres of the two wedges. The power of this bolt on the acute wedges is very great, and the result, when tried on the Great Northern Line, was the occasional longitudinal splitting of the chairs along the bottom. To remedy this, slips of wood were applied between the faces of the chair, and the wedges. The result on the Great Northern Line was unsatisfactory, as the wedges worked loose. The weight of this joint is very considerable; but, notwithstanding, it still requires much more iron to make it strong enough to resist the powerful action of the wedges. As it is, the slip of wood is crushed, and the wedge is pushed upwards. It is difficult to fit such a chair to the rail, and its use does not appear to extend, for it does not produce with the rail "a beam fixed at the ends."

In March 1854, Mr. P. M. Parsons (Assoc. Inst. C.E.) produced a joint chair of considerable size and weight, and of length sufficient to overhang the sleeper on each side. A powerful cast, or wrought iron wedge, of great weight, and about 18 inches in length, is driven between the rail ends and the chair, which, on this side, is lined with a piece of end-grained wood, as a kind of packing, inserted in a rebate, the opposite side of the chair fitting the rail channel. The action of the wedge upon the chair is very great, but Mr. Parsons has provided for this, by introducing strong

circular flanges, dipping below the sleeper, at each end. While the wedge remains tight, the rails are effectively fixed by the ends. This chair has been applied on the Great Northern Line.[1]

In July 1854, Mr. Wright produced what he denominates his vice jaw chair. This chair has one fixed and one loose jaw. The loose jaw is pressed against the rail by a hook head-bolt, passing below the rail, with the nut screwing up against the solid jaw.

A joint, by Mr. Barningham, of Manchester, has been tried on a line in Lancashire. It ought to be effective if made to fit. There are two castings, 2 feet 8 inches in length, filling the side channels of the rails: to and through which they are bolted with six bolts. They are spiked down upon two sleepers, with eight spikes to each joint. This will effectually hold the rails by the ends, but the cost will be very considerable. The section is similar to that of the Author's chair-brackets, with the lips turned under the rail (Plate 2, Fig. 10).

Whether owing to the price of iron, or from a desire to lower the rail on the sleeper, or to get rid of the hard seat on the chair, or all these combined, an experiment was made, on the Rouen line, in December, 1853, of using wood brackets, or knees, to secure the rails to the sleepers. The rail was bedded in a shallow groove across the sleeper, and two pieces of oak timber notched into the sleeper on each side of the rail at an angle pressed end-grain against the side channels, being secured by screw bolts into the sleeper. This was so far approved, that by the end of 1855 there were laid down on various lines,—

	Kilometres.
From Mantes to Caen	30
Fecamp	20
Du Nord	6
D'Orleans, Station of Etampes . .	5
Poitiers à Niort	6
Strasbourg, Parisian Terminus .	8
L'Enett, Alençon	10
Lyons, Dole à Salins . . .	10
Grand Central	50
Total	145

This is analogous to the wood brackets, described and illustrated by the Author in his former Paper[2] (Fig. 14.)

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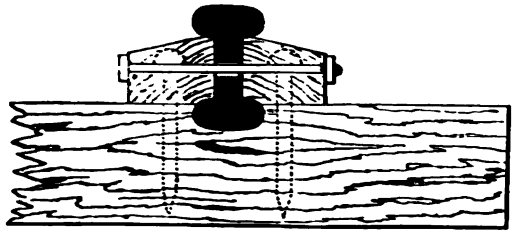
[1] Mr. Parsons' improvements in Permanent Way are explained at greater length, in a Paper by that gentleman, *vide* p. 259.—Ed.

[2] *Vide* Minutes of Proceedings, Inst. C.E., vol. xi. p. 249.

Fig. 14.

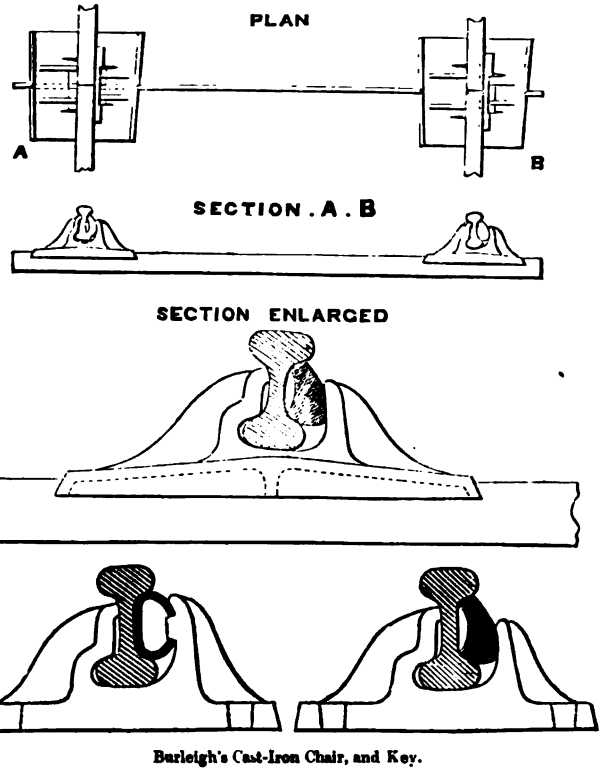


Rail without Chairs.

It is stated, that the saving by substituting wood for cast-iron chairs in France, amounts to about three francs per running metre.

The last joint that the Author is aware of, is by Mr. B. Burleigh (Assoc. Inst. C.E.) (Fig. 15.) It is in use on the Great Northern

Fig. 15.

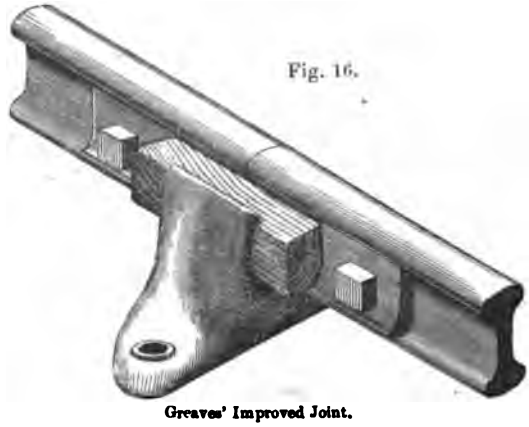


Burleigh's Cast-Iron Chair, and Key.

Railway, and is said to stand well.[1] It is simply a long and heavy chair, with a long and heavy cast-iron key, or an elastic wrought key, judiciously fitted on one side in the channel of the rails, and on the other side bearing against the jaw of the chair low down, so as to put very little breaking strain on it. The angle is very acute, and the keys are placed in the chairs, in such a direction that the action of the trains tends to tighten them.

Mr. H. Greaves has recently introduced some improvements in joints and fastenings. In one case he places one fish in the rail channel in the ordinary joint chair, and secures it by a wood key, and also by bolting it externally to the rail (Fig. 16).

Fig. 16.



Greaves' Improved Joint.

In another plan, a chair with a circular base has a plate to fill the hollow of the rail, and a vertical wood key to secure it (Fig. 17).

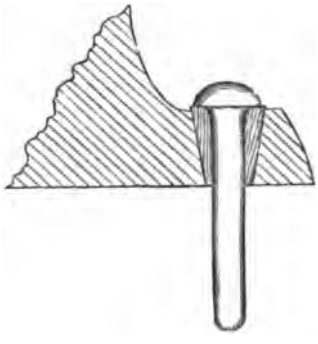
Fig. 17.

Greaves' Improved Chair.

[1] It has since been applied to one of the Indian Railways.—W. B. A.

He has also proposed a method for preventing the head of a chair spike wearing, by surrounding it with a ferrule of wood (Fig. 18).

Fig. 18.



Greaves' Spoke Protector.

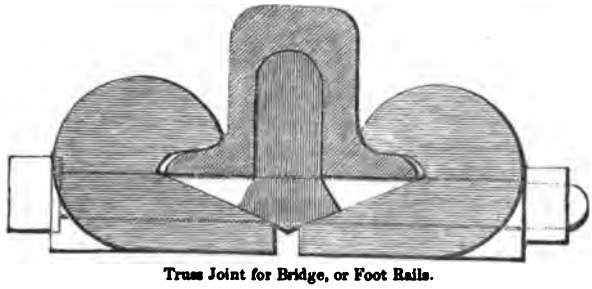
This concludes the various kinds of fastenings used with double I rails.

The foot rail, as originally used, merely rested on the timber, like the bridge rail; but rapid destruction at the joints involved the necessity of a remedy. The common plan was to form a shoe of a bent plate. It is obvious, that there can be no vertical strength in this kind of joint, and that it must bend up and down under constant use. The foot rail was sometimes used in the United States, with a peculiar kind of fish joint, having holes pierced through, so that there was scarcely anything left of the fish. Subsequently, the rail has been increased in height, and a good fish is obtained, but at the expense of a more unsteady rail. The brackets, or knees, previously described (Fig. 11), would support the rail, and at the same time prevent lateral rocking.

The first joint that was adapted to the bridge rail was a dovetail chair; it was used on the Great Southern of Ireland,[1] but it was not effective enough to constitute the rail "a beam fixed at the ends." A subsequent arrangement, was that of putting a simple plate on the sleeper below the joint. This, however, was found insufficient. The next plan was to put a ribbed plate on the sleeper under the rail, and another plain plate below the sleeper, bolting together the rails, plates, and sleepers, with four bolts passing through all. Though the sleepers, which were of the transverse kind, were 6 inches thick and 12 inches wide, they could not resist the pressure of the trains. They were simply a compressible packing; and although the rails were very firm and solid, in other respects, the joints were constantly out of order. In consequence of this, Mr. G. M. Miller, (M. Inst. C.E.,) the engineer of the line, remarked to the Author, that a good joint, similar to that he had introduced for the double I rail, was necessary for the bridge rail. To meet this want, the Author designed the following method (Fig. 19):—Two side castings, each 12 inches in length, press in the angle formed by the rails and the

[1] *Vide* "Description of the Rails, Sleepers, and Fastenings, on the Dublin and Drogheda Railway." By G. W. Hemans. Minutes of Proceedings Inst. C.E., vol. v., pp. 233 to 239.

Fig. 19.



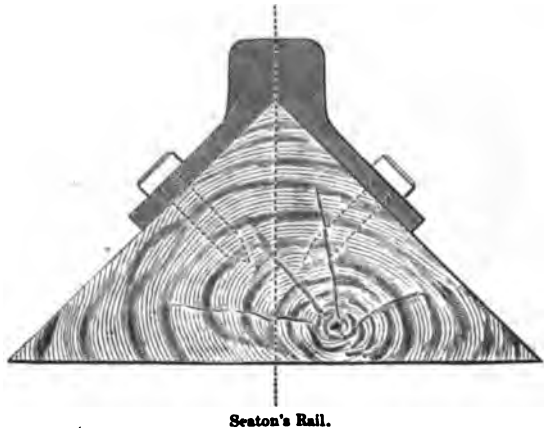
Truss Joint for Bridge, or Foot Rails.

side flanges. An iron tongue-piece, also 12 inches in length, fills the hollow of the rail. Two bolts, $\frac{7}{8}$ths of an inch in diameter, pass through the three castings, and as they tighten, the side castings compress on the inclined plane, where they join, and produce a firm joint which is not found to get loose. This joint forms a base about 1 foot square, under which the ballast is packed, and the expense of providing a new sleeper, 12 inches by 6 inches, to replace that destroyed by wear, is dispensed with; the intermediate cross sleepers, without displacing them, approach nearly to the joint. This system, called the "Truss Joint," is now used on the Great Southern of Ireland, and on the Belfast and Ballymena Railways. It has the advantage of being applicable, without any preparation, or removal of the rails. When used on lines with longitudinal timbers, it is simply required to cut away the timber, to make room for the castings below the rail. Mr. Charles Lanyon, (M. Inst. C.E.,) the Engineer of the Belfast and Ballymena line, has addressed a letter to the Author, in which he remarks, that the experience he has gained of the "Truss Joint" for the bridge rail, enables him to speak very favourably of it, and that he contemplated using it extensively in the renewal of the permanent way of that line.

Mr. G. M. Miller, writing to the Author, said that eighty yards had been laid down on this system, in the autumn of 1854, near Inchicore, and similar lengths, near Athy and Kildare, shortly afterwards. In the following spring half-a-mile was laid on the up line near Strafford. In the latter case the width of the flanges of the rail was reduced, so that the castings did not require to be so heavy. One centre-piece having been broken, it was deemed advisable to replace all the pieces with others of increased proportions. This was done in the summer of 1855. Since then they have stood well. Some have recently been put down with one $1\frac{1}{4}$ inch bolt, which answer well.

In a modification of the bridge rail by Mr. Seaton (Fig. 20), the head of the rail is made solid, and the flanges are bent down

Fig. 20.



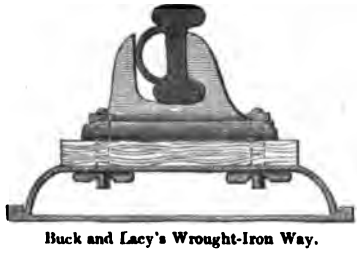
Seaton's Rail.

at an angle of 45°. It is bolted, or screwed, to a triangular timber, with the apex upwards. Mr. Seaton takes credit for reducing the amount of timber by one half, while increasing the bearing surface on the ballast, by cutting the bulks diagonally, and also for increasing the bearing surface of the rail on the timber, from five inches to ten inches, as he seems to assume that the pressure will be on the two faces of the timbers, at right angles, and not vertically.

The uncertainty of the duration of timber sleepers, early induced the use of stone blocks, undoubtedly the best material as a foundation, but requiring some elastic medium between the rail and the stone; for, as it has been remarked by Mr. R. Stephenson, M.P., President, absolutely rigid rails are impracticable for very high speeds.

The failure in the stone blocks, as applied, led to further attempts to construct permanent way wholly of iron. From the first use of iron rails, as tramways, experiments had been made in this direction. In the slate-quarries of Wales, the edge rail proper has long been used, formed of round wrought-iron bars, connected together by iron gauge-bars, and laid upon the ground without sleepers.

Fig. 21.



Buck and Lacy's Wrought-Iron Way.

In 1845, the late Mr. G. W. Buck, (M. Inst. C. E.,) in conjunction with Mr. H. Lacy, produced a system of Wrought-iron Way, in which, "The iron sleepers, whether whole, or in short lengths, may be used without chairs, or with them" (Fig. 21). In the former case a bridge rail,

or a foot rail, may be bolted down upon them; whilst in the latter, the double I rail was proposed to be fixed in chairs, by tubular keys of iron,[1] and the chairs were fastened down to the sleepers, by slot bolts and keys, a piece of wood being introduced between them. The sleepers were inverted troughs, similar in section to one form of the saddle-back rail, subsequently patented by Mr. W. H. Barlow. The trough was formed of sheet iron, with a flat top, and the sides bent down to an angle. When made of thin iron, small tie-rods were used, to prevent the iron from spreading out.

In May 1847, Mr. John Reynolds produced a permanent way of iron,[2] with an internal wood packing, which, in a modified form, was tried on the Great Western Railway. It was generally known, as the system of "hog-trough metals;" they were continuous longitudinals, bearing on the ballast, without the use of sleepers, or stone blocks. This form is steadier in the ballast than the inverted trough of Mr Barlow. This combination of timber and cast-iron is shown in Plate 2, Fig. 9.

In 1846, Mr. H. Greaves brought out the spheroidal iron sleepers, each with its chair cast on it; representing, in general structure, neither the longitudinal, nor the transverse sleepers, but the stone-block system (Figs. 22 and 23). The most recent

Fig. 22.

Greaves' Improved Spheroidal Iron Sleepers.

Fig. 23.

Greaves' Improvements in Fishing.

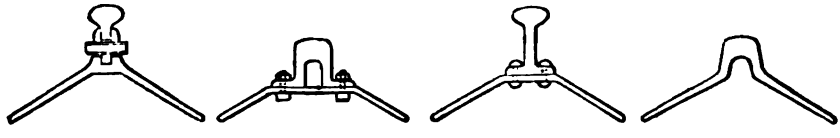
[1] This idea was subsequently patented by Mr. W. H. Barlow, and was described by him to the Institution. *Vide* Min. Proc. Inst. C.E., vol. iv. pp. 49 to 56.

[2] *Vide* Transactions Inst. C.E., vol. ii., pp. 78 to 86.

improvement made by Mr. Greaves in these sleepers is, ribbing them on the outside, and in fish-jointing the rails, placing fishes within the chair-heads, and bolting through the chairs, and also externally to the chairs.

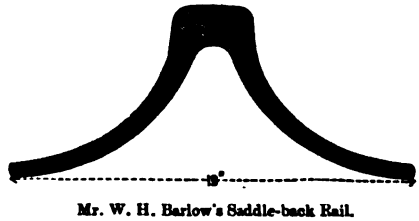
In January 1849, Mr. W. H. Barlow produced a rail, called the "saddle-back rail,"[1] intended to dispense altogether with sleepers, like the "hog-trough system" of Mr. Reynolds, but, in this case, the "hog-trough" was turned upside down. The Author had carefully examined the drawings of this rail, and in his Paper of 1852,[2] he criticised its mechanical qualities, with how much of accuracy the results may now verify. The rail, as specified, is of four forms (Fig. 24). The first is a trough, with the mouth downwards, and

Fig. 24.



with a pair of horns projecting upwards, between which is placed a single T rail, keyed in transversely through the horns and the rail, by tubular iron keys. The second is an inverted trough, with a bridge rail bolted to it. Very great stress would thus be brought on the bolts, as the rail springs under the load. The third is a foot-rail, riveted down to a similar trough, and, consequently, having the same defect in the fastenings. This rail is, also, so much elevated above the base, that it could not possibly be steady in the ballast. The fourth takes the precise form of the ridge-tile of a house. Probably the difficulty, if not impossibility of packing, or keeping such a rail steady in the ballast, led to the next modification—the only one which has been used, and even that can only be kept quiet by a system of sufficient cross-sleepers. The rail, as used, is in fact merely a bridge rail, with an extended base, and the sides placed at an angle instead of being curved (Fig. 25). The first Barlow rails were about

Fig. 25.



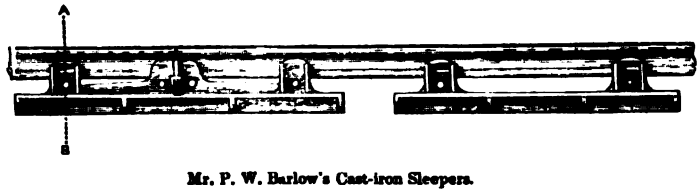
Mr. W. H. Barlow's Saddle-back Rail.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ix., pp. 387 to 401.
[2] Ibid., vol. xi., pp. 244 to 273.

125 lbs. per yard. Whether from any difficulty of manufacture, or simply from a desire for cheapness, they were gradually reduced to 92 lbs. per yard. The original rails were to be held together with angle-iron ties, at intervals of 10 feet. These, it is evident, could neither prevent the rails from rocking, nor spreading; therefore a T-iron tie was first substituted for the angle iron, and after that iron sleepers, similar to the rail itself, at intervals of 9 feet. This being found insufficient, transverse triangular wooden sleepers were finally adopted, the rails being notched into the wood, and held down by dogs. On the Eastern Counties Line, the rails were used with ordinary transverse sleepers. The defects of this rail are obvious. As the head wears, the tendency to spread out increases. The bearing surface on the ballast does not extend to the whole width, as the hollow does not retain the packing, but serves as an inverted cup, to suck up and retain the moisture. The packing is difficult of access, and the necessary opening of the ballast to get the beater to work is considerable; whilst the connection at the joint is the mere riveting together of two thicknesses of boiler plate, affording no vertical strength, unless the ends of the rails abut firmly, without any allowance for expansion and contraction; and even when abutting, the strain on the rivets is excessive. The rail has been laid down on many lines. The Author believes, however, that it is only partially used on the Midland Railway, by Mr. W. H. Barlow himself; that it is not satisfactory on the Welsh lines; and that it is stated, by some French Engineers, to be neither "logical" in theory, nor available in practice.

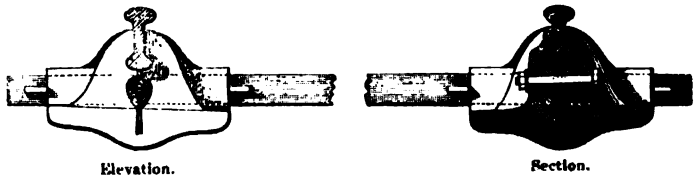
In June, 1849, Mr. Peter W. Barlow, (M. Inst. C. E.,) produced a cast-iron way in two varieties. One (Figs. 26 and 27) was composed

Fig. 26.



Mr. P. W. Barlow's Cast-iron Sleepers.

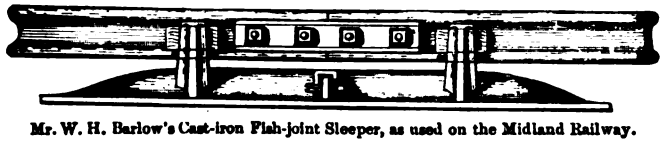
Fig. 27.



Elevation. Section.

of half-plates 3 feet in length, with two chairs cast on them, also in halves, for intermediates, and longer ones with three chairs for the joints, the halves being bolted together below the rails. In the other variety, the plates were solid, with the chairs cast on them, the rails being fastened by keys in the usual way. The object was to make, not merely a chemically durable sleeper, but a cheap one, and to this idea of cheapness the mechanical strength was sacrificed. The system of bolted sleepers was laid down on the South Eastern Line, where the rails were also reduced from 75 lbs. to 65 lbs. per yard, on the presumption that the novel system of intermittent longitudinal sleepers would strengthen them. The result was a failure. On the Londonderry and Enniskillen Railway, the same system was adopted, but the sleepers were nearly double in weight, so that the result was favourable mechanically, but not at a low cost. The cast-iron sleepers, with chairs and wood keys (Figs. 28 and 29), were formed with a

Fig. 28.



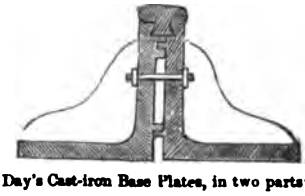
Mr. W. H. Barlow's Cast-iron Fish-joint Sleeper, as used on the Midland Railway.

Fig. 29.

Elevation.

hollow rising bottom, probably to save metal. But this involves one of the objections to the "saddle-back rail," the sucking-up of moisture, which is retained by the impervious iron. In this plan Mr. Barlow was anticipated by Mr. John Day, who in January 1835, specified his cast-iron base-plates in two parts (Fig. 30), the difference being that Mr. Day proposed that the rail-bearing should be continuous, whilst Mr. Barlow used chair-heads.

Fig. 30.



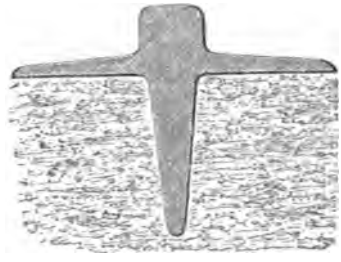
Day's Cast-iron Base Plates, in two parts.

In 1850, Mr. James Samuel, (M. Inst. C. E.,) produced his cast-iron sleepers, with the rails bedded in timber, in rivalry with Mr. Barlow's. The casting was simpler, but the wedging of the wood into the cast iron required great strength of metal to resist it. It was a trough of cast iron, with timber in it, analogous to

the inverted "hog-trough" of Mr. Reynolds, but with the difference of being in short lengths, and not continuous.

In 1851, the Author produced the "Girder Rail" (Fig. 31), both solid and compound, the typical form being a T section, with the broad bearing surface on the ballast, close to the tread of the rails, whilst the depth of the rail was continued with a keel below the bearing surface. In this mode, both vertical and lateral strength were attained, without any tendency to rock, whilst less ballast, probably not one-half, was required; the labour of packing was also reduced to mere surface work, and the drainage was much easier.

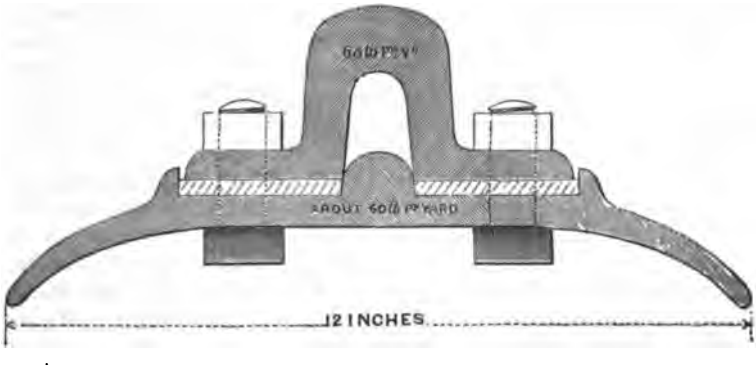
Fig. 31.



Adams' Girder Rail.

In 1852, Mr. J. J. Macdonnell (M. Inst. C. E.) produced a bridge rail, with a longitudinal iron bearing (Fig. 32). The

Fig. 32.

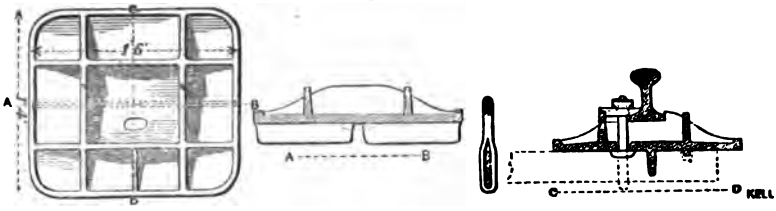


bearing is curved downwards apparently for the purpose of giving vertical strength. A centre and two side-ribs are rolled on the upper side of the plate, between which lie the lower bearing flanges of the rail, resting on strips of timber, the rails and bearers being held together by vertical bolts. It is supposed that these strips of timber will not crush, owing to their confined position between the ribs. It is obvious, that this rail must depend on the ballast for its vertical strength, and that it has a tendency to suck up water below. The joints would be weak, unless stiffened; and probably the best mode of doing this would be, either to bolt a short length of bridge rail below, or else, a deep T iron, making

it take the rail bolts, thus giving about 6½ inches vertical depth. This rail is said to answer well on the Bristol and Exeter Line. The form is evidently much stronger, to resist lateral spreading-out, than that of the saddle-back.[1]

In 1853, Mr. De Bergue, (Assoc. Inst. C. E.,) produced a new variety of iron way, Fig. 33. A foot rail is laid on a series of cast-

Fig. 33.



iron sleepers, formed of a flat table, with a longitudinal rib below. To strengthen the table, a series of thin ribs, as a network, are cast on the upper side. A lug is also cast to take one edge of the rail, and a loose slip, of a wedge-form, with a bolt, is made to take the other side. The bolt has an eye, instead of a head, similar to that shown, in Messrs. Buck and Lacy's specification, in 1845, to take the cross-tie bar below, which is lap-notched into the longitudinal rib of the sleeper. The whole arrangement is very ingenious, producing a considerable amount of strength with very little metal. Mechanically, however, the arrangement is disadvantageous, as the rail is a prop on the sleeper. The joints are fished, and the sleepers are longitudinal, but not continuous. The foot rail, it is obvious, has less vertical strength than the double I, though stiffer laterally, and to produce the best effect, it would be necessary to abut these sleepers one against the other. This system has been tried on the Great Northern, the South Western, and other lines. The flat bearing is an evident advantage, as compared with the "saddle-back rail." If these cast sleepers were in the form of inverted troughs, it would be impossible to keep the line in order. The notch in the lower rib of the casting having been found to be disadvantageous, in a sample subsequently laid on the South Western Railway, Mr. De Bergue divided the lower rib into two parts, and compensated for it by applying an upper rib—a much better disposition of metal, placing the cast rib in compression instead of tension. The Engineer of the South Western line states, after many months' experience, that it has cost less for maintenance than the ordinary

[1] Since this was written the Macdonnell rail has been adopted on the Bridport line.—W. B. A.

way. The area of surface on the ballast is equivalent to a continuous longitudinal way 9 inches in width under each rail.

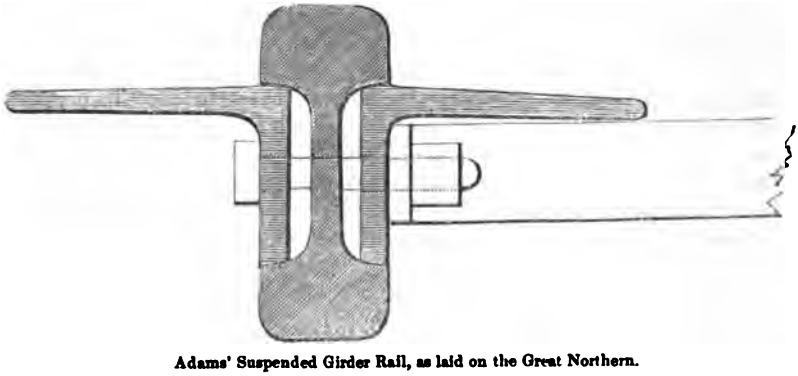
The next system produced was a modification, by the Author, of his girder rail of 1851, in which he has attempted to combine the requisite conditions of lateral and vertical stiffness with easy manufacture and uniform strength throughout. The rail is double headed, the heads being deep enough to clear the wheel flanges, and to allow for wear, without permitting them to infringe on the rail bearers. The vertical rib connecting the two heads, being analogous to the plate girders of bridges, is light. The object is, not to sustain a load upon an insistent web, but to connect the top and bottom tables with such a total depth as will give the requisite strength; while the rail is suspended beneath the upper table, and forms a keel below the bearers, giving firm surface hold in the ballast. The total depth of the rail, as applied, is 7 inches, the heads, or tables, being $1\frac{3}{4}$ inch in depth, and 2 inches in width. This gives, practically, as much bearing surface to the wheel as the ordinary double I rail, of $2\frac{1}{2}$ inches in width, because when by wear more than $1\frac{3}{4}$ inch of width comes into bearing, the sides, which resemble mouldings, crush down for want of support. The early rails were only $1\frac{3}{4}$ inches in width, and were subsequently widened, to give lateral stiffness between the sleepers. The ordinary double I rail, being supported from the base, must necessarily have the vertical rib of sufficient depth not to buckle under the load; and the projecting head being self supported, must have such a form as will tend to prevent it from breaking off. If the side channels were made with square shoulders, it would not be durable. The rail is, therefore, made with a reinforced angle to the rib. But the girder rail having a continuous support on angle brackets, or bearers, throughout its whole length, can be formed with nearly square shoulders to the side channels. The angle brackets are bolted to and through the rails, and breaking joint with the rails, and with each other, produce a very equable strength throughout; whilst the rail, being suspended and not insistent, can be made much lighter than would be possible, were it supported on its lower table in the ordinary method. The angle brackets are about $6\frac{1}{4}$ inches in width, and when bolted to the rail, make up a total width of $13\frac{1}{4}$ inches, equivalent to the bearing-surface of a cross-sleeper road, with the sleepers 2 feet 6 inches apart. Consequently, as the height of the rail-tread is only $2\frac{1}{2}$ inches above the bearing on the ballast, and the keel below is $4\frac{1}{2}$ inches in depth, the maximum security against rocking, or other disturbance in the ballast, is attained. The simplicity of structure is evidenced by the fewness of the parts, being only four types, or forms,—the rail—the bracket—the bolt—and the tie-bar—all of wrought iron. There is very little strain on the bolts, as the

brackets fit securely in the square angles of the rail. The lateral resistance to blows is also considerable.

Experiments have been tried for comparing the strength of the joints of this rail, and the fish-joint of the double I. The force was applied by means of a hydraulic press. The bearings were 7 feet 6 inches apart. With a pressure of eight tons, the fish-joint bolts were broken across; whilst with twelve tons, the girder-rail bolts were unmoved, though the brackets were bent to a considerable angle. With a pressure of twenty tons, applied horizontally across the width of the brackets, the yield was one inch, and within the elastic limit of the rail, which returned to its original position, on the removal of the pressure.

A sample of this system was laid down by Mr. J. Cubitt (M. Inst. C.E.), about the end of the year 1855, on the up coal line of the Great Northern Railway, at King's Cross. The rail is 84 lbs. per yard, and the angle brackets 42 lbs. per yard (Fig. 34). This

Fig. 34.



Adams' Suspended Girder Rail, as laid on the Great Northern.

part of the line is on a curve, and on an incline of 1 in 110, with frequent trains of 300 tons gross. Authority has recently been given to the Engineer, Mr. Brydone, to lay down a further portion of the "Suspended Girder Rail." The ballast used was only one-half the ordinary quantity, and the labour of maintenance is stated to be less than half that of the common way. As the bearing is on the surface, the packing is easy, and on lifting the rails, an extent of about 40 feet is operated on by one leverage. In fact, though not rigid but elastic, this rail forms at the same time a girder and a tension cable. On one occasion, a portion of the ballast was cleared away for 6 feet in length beneath the joint, leaving the rail suspended like a bridge; when very little deflection occurred, during the passage of the engine, the rail being in reality a beam. The laying down is very simple;

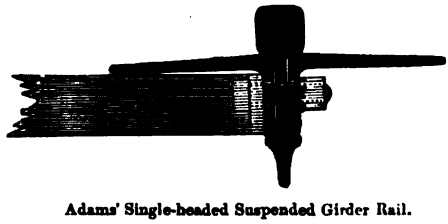
and common labourers cannot make any error, either in the gauge, or in the pitch of the rails, as both are regulated by the tie-bars. The bolts and nuts are firmly held in the matrix, formed of the compressed ballast, and are not subject to move. It is self-draining, the water squeezing away from the horizontal surface-webs, instead of forming ponds below, and the direct entrance of rain is prevented by the overlap on the ballast.

In the processes of "maintenance of way," packing the sleepers is a very important item. In proportion to the elevation of the rail-surface above the bearing-surface of the sleepers on the ballast, so,—other things being equal,—is the tendency to rocking and displacement, and so also is the cost of packing; because the lower the bearing in the ballast, the more material there is to open out in order to pack beneath the sleepers. It is, therefore, obviously important to have the bearing, if possible, on the dry upper surface, instead of below it, supposing that provision is always made to preserve the gauge, and to prevent lateral shifting.

At the recommendation of Mr. R. Stephenson, M.P., President, and Mr. Joseph Locke, M.P., V.P., who have carefully examined the sample at King's Cross, a number of miles have been ordered, for the purpose of laying down on the London and North Western Railway. M. Flachat, (M. Inst C. E.,) the Engineer of many of the French lines, has also ordered a sample to be laid down. Mr. James I. Berkley (M. Inst. C.E.) has recommended it to be tried on the Great Indian Peninsula Railway, and Mr. J. A. Longridge (M. Inst. C.E.) has advised its adoption on the South Eastern and Calcutta.

A variation from the above form is made by using a single-headed rail, with provision below to give bearings to the angle brackets. (Fig. 35.)

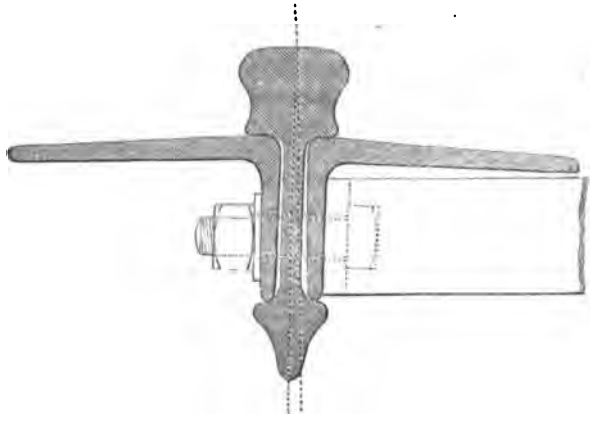
Fig. 35.



Adams' Single-headed Suspended Girder Rail.

The weight of this rail is 62 lbs. per yard, and the single brackets are 31 lbs. per yard. The section adopted for the Bombay and Baroda Railway is shown in Fig. 36, page 254. The depth of the rail is 7 inches. The whole of the iron-work is to be dipped, when warm, in linseed oil.

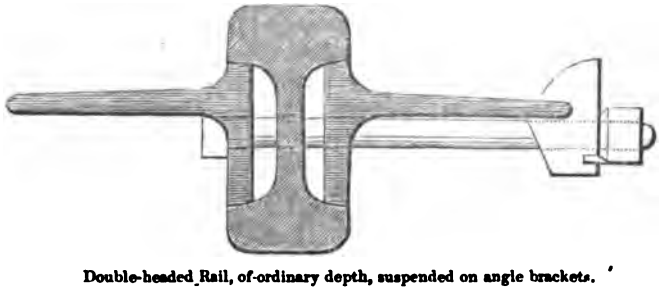
Fig. 36.



Adams' Suspended Girder Rail, to be used on the Bombay and Baroda Railway.

The next sample is an ordinary double-headed rail, 65 lbs. per yard, and 5 inches in depth, the vertical web being diminished in thickness (Fig. 37). The bearing of the angle brackets on the

Fig. 37.

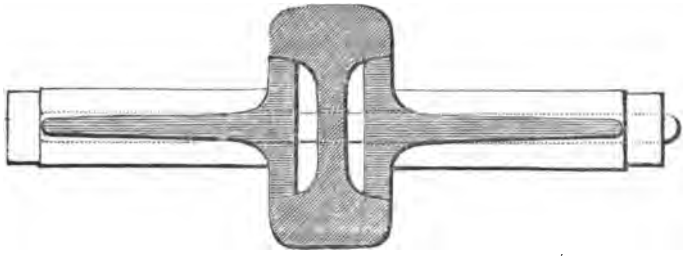


Double-headed Rail, of ordinary depth, suspended on angle brackets.

ballast is 12 inches in width, being equal to a cross-sleeper road with the sleepers 3 feet apart. In order to keep the bolt-holes in the centre of the web, to admit of the rail being readily reversed, the angle brackets are rolled with a projecting lip above; the bolts passing through close beneath the horizontal webs, and the nuts are secured upon small castings, clipping one edge of the angle plates. A small key, driven between the nut and the casting, renders the whole secure.

In another variety, cast T iron angle brackets (Fig. 38.), each 3 inches in depth and $5\frac{1}{2}$ inches in width, are substituted for wrought iron, the castings being about 3 feet in length and weighing 35 lbs. each. Long bolts pass through ribbed projections either at the centre, or at the ends of the castings, or short bolts may be used in recesses, or either keys, or pins, as preferred.

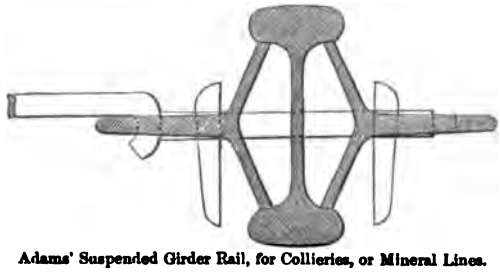
Fig. 38.



Double-headed Rail, with cast T iron angle brackets.

A light girder rail, wholly of wrought iron, and adapted to collieries, or mineral lines, or districts where light engines are used, is represented in Fig. 39. The rail is double headed, 5 inches in

Fig. 39.



Adams' Suspended Girder Rail, for Collieries, or Mineral Lines.

depth, and weighs 40 lbs per yard, the T angle brackets give a width of 9 inches continuous to each rail; an area which, on the South Western Railway, has been found equivalent to a first-class cross sleeper way. The space between the rail and the T angle brackets may be made to subserve the purpose of drainage. The T angle brackets are connected to the rails by bolts and keys 3 feet apart, and tie-bars are applied to any number of the bolts, which are secured by the same keys. The heads of the rails are only 2 inches wide, but they are sufficiently stiffened laterally by the angle brackets, and though the total weight is only 130 tons per mile, an efficient system for moderate loads is attained at a low cost.

The advantages which the Author proposes to attain by this system of Permanent Way are as follows:—

1. The use of tough and elastic material, which, when worn out, has considerable value, entirely dispensing with the decaying timber.

2. A structure of few types and parts which can be furnished complete by the iron-masters, is easily transportable, and needs only the commonest kind of labour to lay it.

3. A continuous bearing on the dry upper surface of the ballast, instead of in a deep trench, which, if non-porous, becomes a pond.

4. Increased vertical strength, without increased weight of rail, and increased horizontal strength with efficient joints. The rails and angle brackets would be arranged so as to break joint, thus forming a strong girder to bear the load, and analogous to an iron cable.

5. Minimum elevation of rail tread above the bearing on the ballast, diminishing the risk of trains getting off the line.

6. Suspension by the upper table instead of insistent bearing on the lower table, so that in the case of a double-headed rail, the tables are not damaged, and the rails can be reversed, end for end, or upside down.

7. A reduction in the expense of laying down, in the quantity of ballast required, and a saving in maintenance.

How far the Author has been successful, or otherwise, in the attainment of these objects is left to the judgment of engineers.

The objections that he has heard of are as follows:—

1. The proximity of the rail tread to the angle brackets, giving facility for placing mischievous obstacles on the line. 2. The chance of ice accumulating near the rail in winter, and thus throwing the train off. 3. The want of sufficient hold in the ground to prevent the rails springing up. 4. The risk of wear and abrasion between the rails and the angle brackets on which they bear. 5. The chance of the bolts getting loose. 6. The difficulty of getting at the bolts to tighten them. 7. The apparent difficulty of bending the rails and angle brackets laterally to suit curves.

On these objections the Author has to observe,—1. As to mischievous obstacles, the facility is equal in the case of all rails. 2. Ice lying on the iron plates would be much more easily broken by the wheel flanges, than ice bedded on and in the ground, by reason of the lessened thickness. Moreover, to set against these mischances, there is the greatly diminished risk, owing to better fastenings. 3. The hold in the ground is of less consequence with a vertically stiff rail, distributing the load over a large space, than with a flexible rail, and there is, moreover, $4\frac{1}{2}$ inches depth of keel roughened by bolts, and connected to tie-bars, to hold in the ballast. 4. Experience shows that the bolts, matriced into the ballast, have no tendency to get loose, and, moreover, they can be readily keyed, to render their fixture absolute. If this is not sufficient, the lower edges of the angles can be dovetailed to the rail, in such a way that all stress is removed from the bolts. 5. The bolts are easily accessible with a ratchet spanner, boring out an opening in the ballast. 6. By cross slotting the angle brackets for two-thirds of their width, at intervals of 3 feet, or by pressing

the angles between the rolls, or by hammering and extending one edge, and corrugating and diminishing the other, any desired curve may be attained.

For countries where timber is cheap and iron dear, girder rails may be prepared with double-heads, and deep side channels, with broad lips, into which timber may be bolted, instead of angle brackets, the joints being formed with wrought-iron angle plates. The rail resembles in form two foot rails, connected by a deep vertical web (Fig. 40).

Fig. 40.

Adams' Suspended Girder-rail, with Longitudinal Timbers.

Mr. Burleigh has had on trial, for about two years, on the Great Northern Railway, a system of cast-iron way, in the structure of which he has displayed great judgment (Fig. 15, p. 240). He forms the cast wedge chair, before described, into a cast sleeper, by extending the base, which presents a wedge form on the plan. Opposite, chair sleepers are connected by a wrought tie-bar, which wedges upon the sleepers, and serves as a tie to strengthen each sleeper while keeping it in position Thus the whole system of fastening is by wedges so arranged that the motion of the trains tends to tighten them. The rails are of the usual double-headed section. This is altogether a simple and effective system of cast-iron way. As a variation, these chair sleepers are sometimes used with an elastic wrought-iron key, made to expand in the driving against a wedge-shape lip on the jaw of the chair.

The last system of iron way produced is that of Mr. Spencer. It is a foot rail, like Mr. De Bergue's, with bolted fishes at the joints. It is bolted down to continuous longitudinal sleepers of corrugated iron; the corrugations being transverse to the rail, and the total width fifteen inches. There is considerable complication of parts. The rail—fish—fish-bolt—a saddle for each corrugation—vertical bolt—joint saddle—rivet—bolt—tie-bar—and tie-bar bolt,—in all nine types, or forms. It has been laid down on the Tilbury Line, and is said to be firmer than the sleeper road. Its great width of continuous bearing, though not laterally stiff, will account for this; but it is evident, that the vertical stiffness can only be supplied by the ballast, and on a yielding structure the line would be a succession of waves. Nor are the corrugations favourable to drainage, as the downward curves on a non-porous stratum would form a succession of small ponds, liable to increase by the bending of the rail vertically.

This concludes the different systems of permanent way, put in practice up to the present time.

The question of cost must vary with times and circumstances. A considerable saving in ballast will afford an increase in iron. It must not be forgotten, that the class of "way" available for engines weghing 15 tons, will not suffice for those of 30 tons and upwards. In a permanent way, or a "way" intended to be permanent, it is a great fallacy to stint material in first cost, and quintuple the expense in maintenance. Even with the cross sleepers, it will be found, that under the increased loads they spring across the middle, the ends rising and falling. If this is prevented by hollowing out the ballast in the middle, the result is diminution of bearing surface on the ballast, and consequent sinking. It will, probably, be found, that cross sleepers, 7 inches in depth and 12 inches in width, by preventing springing, will give greater durability to the timber, and a less amount of maintenance, in displacing fastenings and renewing ballast.

In the foregoing Paper, the Author has confined himself to treating of matters in actual practice, in accordance with the rules of the Institution. In the criticisms, whether of his own productions, or those of other persons, he has endeavoured, conscientiously, to examine them, according to mechanical principles; subject, of course, to the natural bias which every mind must have in favour of its own production. His remarks are now open to the criticism of others, and whilst he believes his own system to possess many and great advantages, he will gladly welcome any new improvement made by others, for facilitating transit, even though rendering his own past efforts useless, regarding it only as an incentive to a further wholesome competition.

The Paper is illustrated by a large number of diagrams, from which Plate 2 and the woodcuts, Figs. 1 to 40, are in part compiled. There are also exhibited models and specimens of most of the systems of permanent way described in the Paper, a great number of which are contributed by the Permanent Way Company.

A Table of particulars of the various classes of permanent way is given in the Appendix, which faces this page.

APPENDIX

Rails.			Mile.	Timber. Cross Sleepers.	Reversible Single or Double Head.	Depth of Ballast.	Class of Bearing.	Total Weight per Mile.
ch. / Bottom.	Height.	Weight per Yard.	ast on.					
nches.	Inches.	Lbs.	ns.			Inches.		Tons.
2½	5	75	40	1,760	Double head	24	Detached	301
2½	5	70	29	1,760	Double head	22	Detached	277
				Cube Feet.				
6	4	84	.	9,201	Single head	23	Continuous	334
6	4	84	.	9,764	Single head	26	Continuous	341
7	5	90	.	4,666	Single head	24	Continuous	252
2½	5½	70	.	..	Double head	22	Detached	263
2½	5	75	6	..	Double head	23	Detached	254
3½	4½	62	9	..	Single head	19	Detached	217
2½	5	65	0	..	Double head	14	Continuous	217
2½	5	72	4	..	Double head	19	Detached	238
12	5½	112	.	..	Single head	17½	Continuous	200
12	6	160 {Rail 75 / B. P. 85}		..	Single head	18	Continuous	265
15	7	122 {Rail 62 / B. P. 60}		..	Single head	19	Continuous	216
13¼	7	168 {Rail 84 / A. B. 84}		..	Double head	14½	Continuous	272
12	7	124 {Rail 62 / A. B. 62}		..	Single head	14½	Continuous	204
9	5	80 {Rail 40 / A. B. 40}		..	Double head	14¼	Continuous	130

ig. 15.
s, February, 1853.
with lip turned
form a Chair.

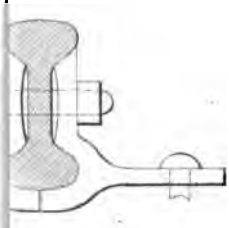


Fig. 19.
P M Parsons March, 1854.
Wood lined Chair.

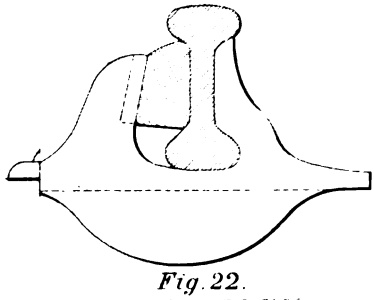


Fig. 22.
W B Adams July 1856.
Recessed Rail for Fishes or Brackets.

evenings, but an abstract of the whole is given consecutively.

No. 959—"On some Recent Improvements in the Permanent Way of Railways."[1] By PERCEVAL MOSES PARSONS, Assoc. Inst. C.E.

IN introducing the subject of Permanent Way, the Author feels it unnecessary to make any remarks respecting the great importance of the subject, or to enter into any detail of the evils which cause expense to Railway Companies, trouble to Engineers, and discomfort to passengers. These are well understood by all practical men. The Author will, therefore, confine himself, to a description of a system recently introduced, which, it is submitted, will, at least, remedy some of the defects that now exist.

It should be stated, that the improvements apply to the kind of road most commonly in use, that in which the rails are secured in chairs resting on cross sleepers; and it is in the construction of the chairs and fastenings, that the improvements are introduced. It should, however, be borne in mind, that their application is by no means confined to wooden sleepers, but they may, with equal advantage, be used with an iron, or any other kind of sleeper.

The chief points aimed at are—First, to secure the rails firmly in the chairs, and to prevent any motion either vertically, or laterally, with the view of avoiding the hammering of the rail on its seat in the chair, and the consequent indenting of its underside.—Secondly, to make a strong and perfect joint, that will require little attention, admit of any adjustment, and derive its strength solely from the chair and fastening, without necessitating an unequal distribution of sleepers to afford it support.—Thirdly, to reduce the chance of the fastenings becoming loose to a minimum, by constructing them of such a form and material as will render them, as far as possible, indestructible, and by reducing the size of such parts as are necessarily of a substance subject to decay, and preparing and using them in a manner best adapted to their preservation.

In devising the best means to secure these advantages, it was considered desirable to retain those parts which experience had proved to be good in the ordinary system, such as the use of wood, as an elastic medium, and the simple mode of tightening the fastenings, by the hammer; all bolts and nuts, and the consequent use of the spanner, being avoided.

It has also been kept in view, so to construct the several parts, as to provide means to compensate for any slight inaccuracies, which must necessarily occur, in those cases in which large quantities of material are supplied from different manufacturers. This

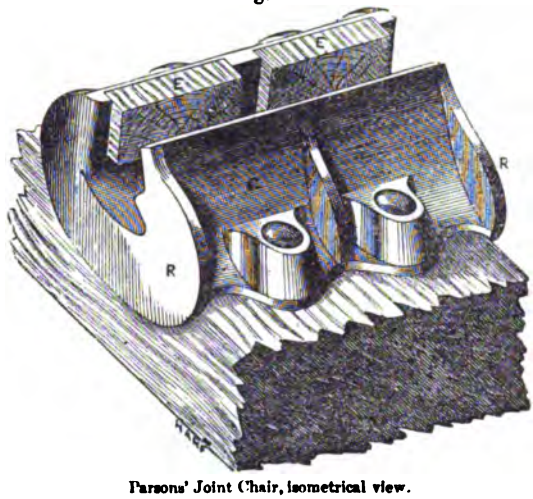
[1] The discussion upon this and the preceding Paper extended over portions of four evenings, but an abstract of the whole is given consecutively.

is a point which is sometimes disregarded, and many even complicated arrangements have been made, to answer with perfect satisfaction, as a first experiment, but have failed, from this cause, to possess any practical, commercial value, when used on an extensive scale.

The attentive consideration of the above requirements has resulted in the system of permanent way about to be described. It was first introduced in 1854, when a short length was laid down on the Great Northern Railway, under the direction of the Engineer-in-Chief, Mr. J. Cubitt (M. Inst. C.E.), with very satisfactory results. It is now being laid down on the East Kent Railway, to which the following description more particularly applies. The rails are in lengths of 21 feet, and are of the ordinary double-headed form, weighing 70 lbs. per yard. The sleepers are of wood 10 inches by 5 inches, and 9 feet in length, placed transversely, at equal distances of about 3 feet apart. No difference is made in the spaces between the sleepers on each side of the joint, and those between the intermediate chairs, it having been found, that the joint chairs were quite sufficient to secure the joints, in a perfect manner, without the assistance of the additional support usually afforded, by bringing the two neighbouring sleepers closer to the joint-chair. It was also considered desirable to have an equal bearing surface throughout, as when this is not the case, and the sleepers are brought closer together at the joints, those parts of the line do not subside equally with the rest, and the result is a series of undulations in the rail, causing the bumping motion so generally experienced, on those lines in which the sleepers are thus arranged.

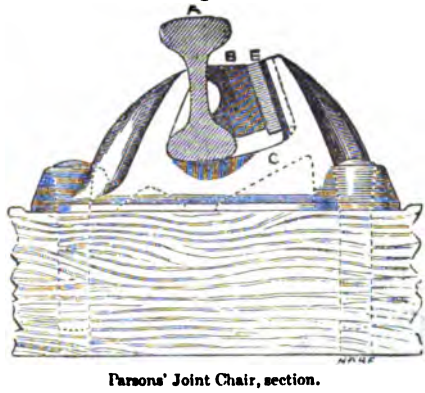
The joint-chairs weigh about 54 lbs. each, and, with the exception of being somewhat longer, are in general appearance similar to ordinary chairs (Figs. 41 and 42). They are 12 inches in length, and the sole, or bottom, is provided, at the underside, with a cross rib at each end, which overhangs the sleeper on each side, and thus forms with the sole of the chair an inverted trough girder, of which the ribs are the webs, and the sole, or bottom of the chair, the flange. By this means the neutral axis is removed to about 3 inches from the bottom of the rail, and thus the whole area of the bottom, or sole, of the chair is brought into tension, by which its strength is greatly increased. The jaw of the chair on one side is made to fit accurately the shoulders of the rails; the other jaw is provided with two recesses, which receive two thin creosoted elm blocks, or cushions, cut across the grain; each block is 5 inches by $2\frac{1}{2}$ inches, and 1 inch thick, and is placed so that the end-grain of the wood bears against the side of the chair, and an iron-wedge fish of wrought iron (Fig. 43)—16 inches long by $3\frac{1}{4}$ inches broad, and tapering in thickness 1 in 24—

Fig. 41.



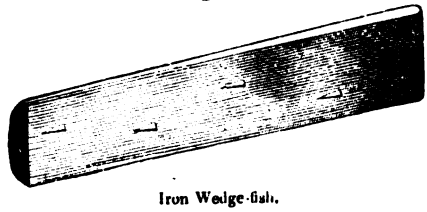
Parsons' Joint Chair, isometrical view.

Fig. 42.



Parsons' Joint Chair, section.

Fig. 43.



Iron Wedge-fish.

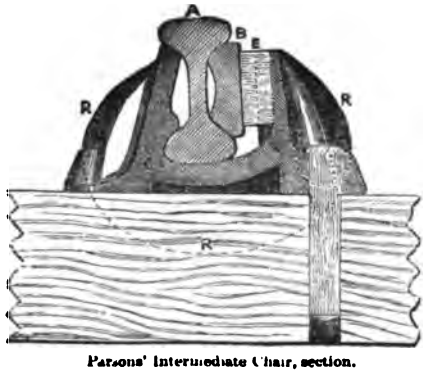
which is driven between the rails and the wood cushions. One side of the wedge-fish is made so as to bear accurately against the shoulders of the rails, and the other side is flat, and provided with four small jags, or barbs, which house themselves in the end-grain wooden cushions just described.

The intermediate chairs weigh about 19 lbs. each. They have a base of $4\frac{1}{2}$ inches by $12\frac{3}{4}$ inches, by 1-$\frac{5}{8}$th inches in thickness (Figs. 44 and 45). In this case the jaw on one side is of such a form, that the upper part presses against the web, and the lower part against the side of the table of the rail; the other jaw has an inward inclination of about one in three, and is provided

Fig. 44.

Parsons' Intermediate Chair, isometrical view.

Fig. 45.



Parsons' Intermediate Chair, section.

Fig. 46.

Iron Wedge-fish.

with a dovetail recess, to receive an end-grain elm block, or cushion, as in the joint-chair. A cast-iron wedge (Fig. 46), 5 inches long by $2\frac{1}{2}$ inches deep, and tapering about 1 in 20, is driven in between the end-grain cushion and the rail. This wedge is provided with jags, or barbs, similar to those on the wrought-iron wedge used with the joint-chair, but instead of fitting against both shoulders of the rail, it is made to bear against the web of the rail, and the upper part of its lower shoulder, by which means, in conjunction with the inclined jaw, the rail is forced down upon its seat, and firmly held laterally at the same time. The chairs were cast by Jobson's moulding machine, with great accuracy.

The taper of the wrought-iron wedges for the joint-chairs is produced by means of rolls, three wedges being formed at each revolution. They come out in bars containing ten or twelve wedges each, which are cut off by means of a circular saw. They are then roughly trimmed by hand, and finally straightened and taken out of 'winding,' by being placed in a trough planed out of a cast-iron block, under a swage of the same length, on which a weight of about 50 lbs. is allowed to fall, or pressure is applied.

In considering the peculiar advantages of this system, it is necessary to draw attention to the end-grain wood cushions. It will be understood, that they are cut in slices across the grain, in such a manner that when placed in the chair, the fibre of the wood will be crossways, or at right angles, to the rails, and will thus sustain the pressure of the wedge on the ends of the grain, or fibres, or in the direction of their length, instead of sideways as in the ordinary wooden key. Although, at first sight, the mere change in the position of the fibres may appear trivial, yet on considering the principles, and investigating the facts, in connection with the mode of application, it will be found, that many important advantages result from it. The first and most obvious is, that as wood does not shrink materially in the direction of its length, or endways of the grain, it is evident that the wedges will not become loose from the heat, or dryness of the weather, nor indeed be influenced by the most violent atmospheric changes. This has been fully confirmed by experience, for notwithstanding the chairs on the Great Northern Railway were put down in wet weather, and have been during the last two years exposed to every variation of temperature, both of dryness and moisture of the atmosphere, not the slightest approach to loosening has been detected. Another advantage of using the wood endways of the grain, is the superior power it possesses to resist compression, in comparison to the usual method of applying it sideways, as in the ordinary wood key. It also presents a certain degree of roughness on the end-grain, which affords a good hold

for the keys, and the jags, or barbs, with which the keys are provided, further tend to secure them in their places.

The action of the jags is as follows:—When the key is driven, the points of the jags force aside the fibres of the wood, which gradually close up behind the square ends. They thus become housed, or embedded, in the wood, and before the key can be withdrawn, they have to cut, or plough, their way out; and to effect this requires the application of a considerable amount of force.

This arrangement is so efficient, that the probability of the keys becoming loose becomes very remote; and it allows a much greater amount of taper to be given to them with safety, than is usually the case in the ordinary wooden keys. Thus, instead of a taper of 1 in 40, or 1 in 50, which is about the average given to wooden keys, these are made 1 in 24, which allows a sufficient margin to cover any unavoidable inaccuracies, or difference, in the sizes of the parts fitting together, and also provides a sufficient amount of draught to tighten up the fastenings, should such be required, without the necessity of substituting new ones.

If, however, the wedges should at any time require tightening, a simple blow with a hammer is all that is required, thus obviating the use of spanners, and the consequent stooping and careful manipulation indispensable with those fastenings in which bolts and nuts are used.

By employing the wood in the manner explained, it is preserved from decay a much longer time, than when used in the form of the ordinary wooden keys, as the ends of the sap vessels being covered on one side by the chair, and on the other by the iron key, it is effectually protected against the admission of moisture. Moreover, owing to the thinness of the cushions, they become sufficiently impregnated with creosote, by simple soaking, and are thus rendered extremely durable.

The chief advantage of the wooden key,—its elasticity,—is also possessed by the end-grain cushions, whilst the iron wedges will stand harder driving without injury, and thereby fix the rails more firmly in the chairs. Moreover, the action of the wedge being to bring the rail firmly upon its seat in the chair, besides fixing it laterally, all hammering of the rail on the bottom of the chair is prevented, and the underside of the rail is preserved fit for use, when the upper one is worn out. The indenting of the rails in the ordinary chairs is caused, it is well known, by this hammering action, arising from the insufficiency of the wooden keys to keep them firmly upon their seats.

The preceding remarks apply to the intermediate as well as to the joint-chairs. There are, however, some other peculiarities in the construction of the latter which are deserving of attention. The

length of the chair insures a sufficient hold of both the rails, and the mode by which they are secured, by the chair on one side, and the iron key on the other, both laterally and vertically, renders any motion at the joint impossible.

By the addition of the lower ribs the chair is made sufficiently strong, with the least quantity of metal, to resist the severe strain to which it is subjected by the driving of the wedge, and the pressure applied to the rails is equal to that obtained by any known mode of fastening, and exceeds that which any ordinary chair could bear.

The various imperfections which have been found to exist in the usual mode of fastening has led to the impression in the minds of some, that one of the conditions necessary for a good joint was that it should be in a state of suspension. This, it is contended, is a conclusion, which has been arrived at too hastily, and it can be shown, that the position of the joint is of but little importance, provided the fastenings are commensurate with the duty they have to perform. The difficulty consists, in fact, not so much in making a good joint, as in subsequently maintaining it in the state of efficiency required. Many examples may be cited, of roads laid with ordinary joint-chairs, of greater width than usual, and compressed wooden keys, in which the joints were as perfect and free from motion when newly laid as could be desired; but they soon became imperfect, simply because the wooden keys were insufficient to resist the combined strain of the ends of the rails, tending to cut into and compress them. This shows that failure arises from the inadequacy of the fastenings, and not from the position of the chair, in respect to the joint.

In the new form of chair, nothing of this kind can take place; the chair and the iron key between which the rails are confined are both indestructible, and are capable of resisting the tendency of the rails to motion; while all the advantage derived from the use of wood, as a cushion, is retained, the strain is by means of the iron wedge spread equally on its whole surface, which is of ample area to bear it without injury.

The great extent to which railways exist over all portions of the globe, and the expense of maintenance forming so important an item in railway expenditure, will, the Author trusts, be a sufficient apology for having entered somewhat minutely into the peculiarities of the system described, as he is convinced that any improvement which has for its object safety and economy will always be impartially investigated by the Members of the Institution of Civil Engineers.

The Paper is accompanied by a series of Diagrams, from which Figs. 41 to 46 have been compiled.

Mr. P. M. PARSONS, after describing the rolls employed for producing the tapered wrought-iron wedges, used with the joint chairs on his system of permanent way, now being laid on the East Kent Railway, remarked, that Mr. Adams' paper omitted all notice of the class of fastenings employed previous to the introduction of the wood key. This class consisted either of iron pins, small iron wedges, or screw bolts, all embodying the same principle of small metal surfaces, bearing upon small points of contact. The fit was generally very imperfect, owing to the unyielding nature of the materials and the inevitable imperfections of the surfaces, so that the fastenings rapidly deteriorated. When, from any irregularity of fit, an undue strain came upon the bolt, the thread of the screw was stripped, or the nut took a particular set, to which it always returned even after being screwed up.

These fastenings were abandoned simultaneously by all Engineers in favour of the wooden keys, which were the very reverse in principle, presenting an elastic medium to compensate for inaccuracies, and bringing comparatively large surfaces into contact. The wood keys, or wedges, were first tried, as an experiment, in 1835, on the Liverpool and Manchester Railway, under the direction of Mr. Locke, M.P., V.P., previous to their general employment on the Grand Junction Railway, with the double-headed rail designed by Mr. Locke, at the same time, and first used on that line. If wood keys had not possessed some decided advantage over the old system of screw bolts and pins, he thought they would not have been so unanimously adopted, by so many practical men. That he considered to be an important fact, and one well deserving attentive consideration.

Mr. Parsons was led to make these observations from the circumstance, that the whole of the arrangements proposed by Mr. Adams, with a view of superseding the present plan, depended entirely on screw bolts and nuts, and as he thought, to a dangerous extent. If the bolts failed, the whole permanent way went to pieces, and at the best their efficiency could only be maintained by unremitting care and attention, involving considerable expense. Most Engineers knew the style of screw bolts which were obtained at the present time, for fastening the parts of the permanent way together. They were manufactured and sold by the ton, and were of necessity very imperfectly made. He did not mean to say, that a screw bolt could not be produced to perform its office properly, but the price at which (on the score of economy) it was necessary to purchase them, precluded their being made in a proper manner. A screw bolt, to be efficient, ought to have the thread of the bolt and the nut accurately fitting each other. In fact, the bolt should be turned, and the hole rimered out to insure perfect adjustment. The face of the nut and the bolt-head ought both to be

square and flat; and to secure this the nut and the shoulder of the bolt-head should both be faced in a lathe, or machine. The bearing surface for the nut and bolt-head should also be flat, and square with the hole, to insure a fair bearing. Unless these points were attended to, it was probable, that by far the larger portion of the bolt-heads and the nuts would only take a bearing on one side and on a small surface. That such was the result of the bolt and nut system, in a majority of instances, was notorious; he had been invariably so informed by plate-layers, and had witnessed it himself on many occasions.

Recently he had examined some of the brackets, or fish-plates, on the Great Northern Railway, which had been laid down about twelve months, and were secured by bolts and nuts. This examination showed, that in one hundred and twenty-five pairs of joints, each pair having eight bolts, two hundred and sixty-one bolts were loose, and six were out altogether, though they had been tightened up within 48 hours. The number of loose bolts at each joint varied from one to eight. He therefore contended, that such bolts and nuts as were ordinarily used, were unsafe, inefficient, and expensive fastenings, for connecting together the parts of a permanent way, and that they were not to be relied on.

In discussing a point of this kind, it was natural to inquire, what was the office of a bolt? It was simply to bind certain parts together. Then was a bolt the simplest and most efficient means of doing this? He argued that it was not, and that the iron wedges, in connection with the end-grain cushions, described in his Paper, were preferable. They were always capable of performing their office, and were tightened up by a blow of a hammer. Each wedge had a bearing surface of $6\frac{1}{4}$ square inches in the intermediate and 25 square inches in the joint-chairs, whereas in a bolt, it would probably not amount to $\frac{1}{4}$ of a square inch, and if screwed up beyond a certain point, the thread would strip, and the bolt be spoiled. The wedges for the intermediate chairs, weighed about 4 lbs. each, and cost $2\frac{1}{2}$ pence. The creosoted elm blocks, or cushions, cost about one farthing each, and were calculated to last fifteen years. With these blocks, and a suitable chair, each wedge would exert a pressure of from $2\frac{1}{2}$ to 3 tons. Now, a bolt, $\frac{7}{8}$ths of an inch in diameter, to put on the same pressure, would weigh $1\frac{1}{2}$ lb., and as the cost of bolts was now £28 per ton, or 3 pence per lb., each bolt and nut would cost about $4\frac{1}{2}$ pence.

With regard to the objections which had been made to the chair system, he must confess, that he did not know of any instances in which the rails were supported by the keys. He had found that, generally speaking, the key simply held the rail sideways, whilst the chair offered a fair surface for the rail to rest upon. In the

intermediate chairs on his system, the action of the key was to force the rail down on its seat in the chair, as well as sideways against the jaw, so that the injurious hammering of the rail on its seat, which had been spoken of, could not take place. The surface of the rails was 6⅝ inches above the sleeper, and the chairs were 12½ inches in length.

With regard to the "girder" rail, he did not see why it should have received that designation, as all rails were girders, the difference between the "girder" rail, and the ordinary double-headed rail, being in the dimensions only, and not in the principle. The "girder" rail had a depth of 7 inches, whilst the double-headed rails in general use had a depth of about 5 inches. Now, experience had proved that the latter was sufficient for the weights which had to be carried, with bearings 3 feet apart; for the deflection of a rail of 70 lbs. per yard suspended between chairs 3 feet apart, would not, he believed, exceed ·025 of an inch, with an engine having 10 tons weight on the driving wheels. This was scarcely more than the thickness of a scale of iron. If a rail of greater depth was adopted, and it was supported along its whole length, then there would be an injurious amount of rigidity, for practical purposes. The upper surface of the rail would soon laminate and be destroyed, owing to the want of a sufficient amount of elasticity. This he had noticed was already the case, with the rails of this kind on the Great Northern Railway, although they had only been laid a short time. He had heard of an engineer who, in cutting through a bed of sandstone, placed the chairs upon the rock, and the result was, that the rails were destroyed at a very rapid rate. The effect of deepening and reducing the thickness of the middle web, would be to increase the cost of the rails at least £1 per ton, owing to the greater difficulty induced in the manufacture. He believed, that the middle web of a rail, to be kept within the ordinary market price, should not be much thinner than ⅜ths of an inch.

It had been stated, that the cost of a line laid with the "girder" rail, angle brackets, cross ties, and seven thousand and forty bolts and nuts, would be £2,197 per mile; the cost of ordinary rails and chairs on the system which he advocated, with cross sleepers (creosoted), would not amount to more than £1,645 per mile. Now, if this difference in first cost, or £552, was put out at compound interest, at the end of twelve years, (by which time the sleepers, trenails and cushions would probably require to be renewed), the sum of £438 would have accumulated, which with the value of the old sleepers would be more than sufficient to effect the renewals, without touching the sum of £552 originally invested. This might be carried on to an indefinite period, and when the whole of the rails, chairs, &c., had to be renewed, the £552 would be partly available for that

purpose, so that the increased cost of the "girder" rail system would more than outweigh any advantage, that might arise from the greater durability of the material employed. It had been supposed, that the bolts and nuts on the "girder" rail system would last twelve years, but from what he had observed, he thought it probable that they would require to be renewed long before that time. Each renewal would entail an additional cost of about £70 per mile for materials, exclusive of the labour of taking them out, putting them in, and the constant tightening they required. Looking therefore at the question on the score of economy, exclusive of the injury the rolling stock and the rails would sustain from excessive rigidity, he could not see any advantage in the "girder" rail system; and though credit had been taken for a saving in the quantity of ballast, Mr. Parsons did not think engineers generally would consider it either safe, or wise, to diminish the amount of ballast on a railway.

Mr. P. W. BARLOW wished to reply to the assertion "that the result of the experiment of his cast-iron sleepers was a failure on the South-Eastern Railway, while on the Enniskillen Railway, where they were double in weight, the result was favourable mechanically, but not at a low cost." This was not an accurate statement. It was true that the Enniskillen sleepers were increased in weight beyond what was originally intended; but, the lightest road on the South-Eastern Line, was still 5 per cent. heavier than the heaviest portion of the Enniskillen, and the average was 18 per cent. heavier. The rails on the Enniskillen line were 60 lbs. per yard, whilst the lightest on the South-Eastern were 70 lbs. per yard, and the heaviest were 80 lbs. per yard. The weights per mile were:—

		Tons.	Tons.
South Eastern.—Heavy road;	Rails . .	126	287
	Sleepers .	161	
Light road;	Rails . .	110	255
	Sleepers .	145	
Enniskillen.—Heavy road;	Rails . .	94	239
	Sleepers .	145	
Light road;	Rails . .	94	212
	Sleepers .	118	

With reference to the experiment on the South-Eastern Railway, which had been denominated a failure, the facts were, that in 1850 and 1851, one hundred miles of his iron sleepers were laid, of which about ten miles had been taken up, having been principally laid with old rails; and these were of the arched form, but not lighter than the others. This road was defective from the old rails not fitting the joint sleepers, and thus a blow took place on the passage of a train, producing a hard and unpleasant road,

and causing breakage of the joint sleepers, unless care was taken by the platelayers. He was not aware of a single instance of an intermediate sleeper having broken. For heavy traffic and high speeds, he recommended that the joint sleeper should be abandoned, in favour of two intermediate sleepers and the fish joint, as this could be effected without increase of cost.

The first cost of the heaviest road on the Enniskillen Line did not exceed that of an ordinary timber sleeper road fished; but the lightest road was sufficiently strong for the ordinary traffic, which, though light, compared with English lines, consisted principally of goods. This railway was, with the exception of ten miles, a single line. The length of road laid with the cast-iron sleepers was forty-six miles. The portion of the road on which the light cast-iron sleepers had been used, had only been in operation five years, and there were six trains daily each way. The engines weighed about 22 tons, and the speed maintained was twenty miles an hour. The cost of maintenance, during the last half year, including bridges, ballasting, and stations, was £1,144, or at the rate of £32. 14*s.* per mile of single line per annum. On the Coleraine Line, there were fifteen miles of road laid with the cast-iron sleepers, the maintenance of which was let for 9*s.* 6*d.* per mile per week, or at the rate of £24. 14*s.* per mile of single line per annum. It might be said, that these results were no test for English traffic, but he believed, there were many miles of railway yet to be constructed, where the traffic would not exceed that on the Enniskillen, for which this construction was peculiarly adapted, as it had been proved, that one half the cost of renewal and maintenance was saved. From some recent experiments he could state, that with a heavier rail, fished, this description of road was sufficient for the heaviest traffic.

Mr. Adams had omitted to state in his Paper, that, on the Midland Railway, there were fifty-four and a half miles laid with the cast-iron sleepers, and exposed to the heavy traffic of that line. They had been laid from four to five years, and were still in good order. They were generally of the arched form, and rather lighter in weight than those used on the South-Eastern. On the East Lancashire, and the Eastern Counties Railways, ten miles had been laid with these sleepers. Altogether two hundred and twenty-five miles had been laid on this system, for an average of five years, of which little, if any, more than 5 per cent. had been renewed, or 1 per cent. per annum from all causes, including imperfect casting, bad ballast, neglect of platelayers, and the ten miles of defective road on the South-Eastern previously alluded to.

In regard to other cast-iron sleeper roads, it was due to Mr. Greaves to state, that his spheroidal sleepers had been adopted extensively on many foreign lines, and to some extent in England.

ED RAIL.

Number of Experiment.		Width.	Weight.	Bearing Surface.
		ft. in.	Lbs.	Sq. in.
1	Cast-iron half-sleeper, bolted under t	2	131	532
2	Cast-iron half-sleeper, bolted under t	2	131	532
3	Cast-iron half-sleeper, bolted under t	2	130½	532
4	Cast-iron half-sleeper, with wood cu	3	182	795
5	Cast-iron half-sleeper, with wood cu	3	182	795
6	Cast-iron half-sleeper, with wood cu	2	137	532
7	Cast-iron half-sleeper, with wood cu	2	137	532
8	Cast-iron sleeper, with wood cushion	3	127	810
9	Cast-iron sleeper, with wood cushion	3	127	810
10	Cast-iron altered pattern of sleeper,	3	141	885
11	Cast-iron third pattern of sleeper, wi	3	151	900
12	Cast-iron third pattern of sleeper, wi	3	151	900
13	Cast-iron ordinary intermediate sleep	1½	147	756
14	Cast-iron ordinary intermediate sleep	1½	147	756
15	Cast-iron sleeper, with wood cushion	3	182	900
16	Cast-iron sleeper, with wood cushion	3	182	900
17	Cast-iron timber-bedded sleeper, as l	4	156	672
18	Cast-iron timber-bedded sleeper, as l	4	156	672
19	Cast-iron timber-bedded sleeper, as l	4	132	672
20	Cast-iron sleeper, with wood cushion	3	155	810
21	Cast-iron sleeper, with wood cushion	3	153	810

ERS.

22	Transverse cast-iron sleeper, with wo	1 0 1 0	164	318 318 636
23	Transverse small sleeper, single chair	1 1¼	96	405
24	Transverse small sleeper, single chai	..	82	405
25	Transverse (Pernambuco Railway) ci	..	119	380
26	Transverse (Pernambuco Railway) ci	..	88	380

OMED RAIL.

27	Flat corrugated cast-iron sleeper with	1 3	128	900
28	Flat corrugated cast-iron sleeper, wit	1 3	122	900
29	Flat corrugated cast-iron sleeper, wit	1 3	123¾	900
30	Flat corrugated cast-iron sleeper, wit	1 3	116	900
31	Curved corrugated sleeper, without w	1 3	73	360
32	Curved corrugated sleeper, without w	1 3	73	360
33	Mr. De Bergue's cast-iron sleeper for cashire and Yorkshire Railways, te	1 2	46¾	280
34	Mr. De Bergue's cast-iron sleeper for cashire and Yorkshire Railways, te	1 2	45¾	280
35	Mr. De Bergue's cast-iron sleeper for cashire and Yorkshire Railways, te	1 2	48	280
36	Mr. De Bergue's cast-iron sleeper for cashire and Yorkshire Railway, tes	1 2	56	280

Mr. De Bergue's sleepers had also been laid extensively, and with very satisfactory results, as compared with wooden sleepers.

It had been shown by the President,[1] that about two millions of wooden sleepers required to be renewed annually, which would cost about £450,000. Now, it was desirable, that this heavy expenditure should be saved, and he maintained that the experience with the cast-iron sleepers so far, had shown how this might be accomplished. It had been proved, that the maintenance was much less than that of an ordinary wooden sleeper road, and the durability was unquestioned. He thought, therefore, that this experiment, on a comparatively new principle, could not be regarded as a failure, but on the contrary, it demonstrated that the ordinary wooden road would, before long, be superseded by cast iron.

If the cast-iron road was found to be more rigid in practice than was desirable, it might be completely remedied by the system proposed by Mr. J. Samuel, which consisted of introducing wood cushions between the half sleepers. An experimental length on this plan had been laid for six years on the Eastern Counties Railway.

With the view of testing the strength of the different forms of cast-iron sleepers, an extensive series of experiments had been made at Derby, for which purpose a ram, weighing 12 cwt., was employed. Twenty-three forms had been experimented upon, and the result was, that an ordinary rail weighing 80 lbs. per yard, with 3 feet bearings, was destroyed, by bending, with a fall of 2 feet, whilst the South-Eastern cast-iron sleeper bore a fall of 4 feet 6 inches, being one foot more than any other which had been tried. A summary of these experiments was given in the accompanying Table.

Mr. HEMANS thought great credit was due to Mr. Adams for the invention of the fish-joint,—but in his opinion, the merits of that contrivance had been exaggerated. It was described as producing an effect analogous to a beam fixed at both ends, but he could hardly realise that idea. A beam fixed at both ends he understood to be, one so tied down to immovable abutments, that whatever weight might be put upon the centre of the beam the ends could not rise. He did not think this was the case with a rail under pressure, as the advancing wheels producing deflection in the middle caused the ends to rise, and then the adjoining rails and sleepers were raised, the ballast acting as the fulcrum. He doubted whether any great additional strength was given to the rail by the fish-joint, although it conduced to the smoothness of the rolling surface, and thus imparted an equable motion, and increased the

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xv., p. 127.

safety of travelling. He had used it to a considerable extent with satisfactory results. The tendency of the rails to overturn, in consequence of the oscillation of the engine, and the blows from the flanges of the wheels, had also been overrated. The principal effect of these oscillations was a tendency to widen the gauge. Much time and labour had been wasted in the endeavour to improve cast-iron chairs. The two objects which seemed to have been present in the minds of those engaged on their improvement, were to increase the bearing on the sleepers, and to prevent the overturning of the rail, from the action of the wheels. It was important to extend the bearing upon the sleeper; but, in order to effect this, it was not necessary to expend £500 per mile for cast-iron chairs, especially when bridge and other flat-bottomed rails could be fixed by screws and bolts, directly upon the sleepers. These rails were always inclined in a direction contrary to overturning, and they were undoubtedly kept down by the weight of the engine. It had been supposed that the double-headed rail would be capable of being reversed, but this could not be done advantageously, as the lower side was always more or less indented from the pressure on the bearing point, and therefore operated injuriously on the rolling stock. He had used in Ireland, and had seen on the Continent, hundreds of miles of rails attached to the sleepers without any chairs: and even where the base of the rail was less than the height, these rails had never overturned, nor had they shown any tendency to move. It had been argued, that great advantage would result from placing the surface of the rails lower than usual. He did not believe that this was at all important, and one great practical difficulty would occur in consequence. When the surface of the rails was close to the ballast, the wheels were rendered greasy by the mud, in the frequent cases of impure ballast, which was splashed over them in wet weather. This had often been observed with the bridge rails laid upon longitudinal timbers.

Mr. James Samuel's cast-iron trough, lined with a wooden cushion, to be used with a double-headed rail, seemed to have merit. In that case they had the imperishable sleeper, the break of joint, the wooden cushion, and every facility for reversing the rail, when the upper table was worn. Unless the expense of that system was too great, he thought it should be tried.

Being anxious to get rid of the perishable sleeper, he had tried five miles of Mr. W. H. Barlow's "saddle-back rail" of 100 lbs. to the yard, and was sorry to be obliged to pronounce it a failure. It formed a very rigid way, and, he believed, the surface of the rails was rapidly injured from the absence of elasticity. Perhaps the rails he used were not quite so well rolled as they might have been; but he found, for a considerable distance, the whole surface of the rail torn off. He had been informed, that

the same results had occurred on other lines where this description of rail had been used. Another defect was, that it had too little hold in the ballast. The blows of the wheels in travelling soon caused the rivets to get loose, so that bolts which could be tightened up had to be substituted. With regard to Mr. Adams' rail, it appeared to him to be one of the best inventions for an entirely iron way that had been brought forward. It was very strong, and had a good hold of the ballast; at the same time, he could not see how the bolts were to be kept fast, as they were entirely out of sight, under the flanges, and were buried in the ballast, so that when they became loose, as undoubtedly must occur, the ballast would have to be disturbed. Bolts had a constant tendency to become loose, especially on curves, and under this system, this might go on to a great extent before the mischief could be detected.

On a portion of the Dublin and Galway Line, of about twenty-five miles in length, which passed through a soft and boggy soil, he had adopted bridge rails, with longitudinal timbers, and a fish-joint,—not like that of Mr. Adams', but simpler and lighter, though perhaps not of the same strength. Each joint had four rivets, and one long bolt which was passed through the rail, fish-plate and longitudinal sleeper, so that the joint was rendered quite immoveable. He admitted, that it was not so strong as the cast-iron bridge rail joint; but in the situation in which it was applied, he found it extremely effective, solid, of sufficient strength, and trains ran easily over it without blows at the joints. The expense of the plan was inconsiderable. He had used it, with some modification, over the whole of the Midland Great Western Railway of Ireland, now about one hundred and eighty miles in length.

Mr. ROBERT RICHARDSON asserted his claim, as the joint inventor, with Mr. W. B. Adams, of the "fish-joint" for rails. He produced correspondence with Mr. Adams in the years 1846-47, in which the invention was discussed. This invention was afterwards brought out and secured to them by patent as the joint-inventors.

Mr. J. K. ARTHUR remarked, that the rigidity of the iron way, and the effects mentioned by Mr. Hemans, did not in the least apply to the Londonderry and Enniskillen Railway. Upon the general question of the rigidity of iron roads, he could give no opinion; but he could state, that the travelling upon the iron portion of the line he had mentioned, was preferable to that upon the portion where wooden sleepers were employed. The run of the carriages was smoother and more agreeable; the noise less, and the comfort to the passengers greater. Mr. Adams, in the Paper under discussion, had described the iron road upon this line as "mechanically successful." The practical experience of nearly

five years' working had proved the correctness of this opinion. Mechanically its success was perfect. Some doubt had been suggested, as to whether the prime cost had not been too great, but after the explanation given by Mr. Barlow, respecting the comparative weights of the sleepers on the South-Eastern and the Enniskillen Lines, he thought this impression would be removed. With regard to the alteration of the sleepers during the progress of the works, he thought it but just to state, that all the officials connected with the working of the line were of opinion, that the best portion of the line, and the easiest maintained, was the section from Strabane to Newtown-Stewart, which was laid with the exact pattern and weight recommended by Mr. Barlow. The evidence obtained, from year to year, of the small annual cost, at which the road laid on this system could be maintained, and the certainty of great saving in renewal, had satisfied those interested in the Companies, that not only was it mechanically, but financially, successful.

Mr. BURLEIGH remarked, that as allusion had been made to the trials on the Great Northern Line, he would state a few facts which might not be uninteresting. A small length of the line was laid down with Mr. Parsons' chairs, with end-grain wood packing, and the result of the trial was favourable. The wood cushions firmly sustained the wedges, although he had been told that one, or two of the cushions had split and become loose, owing to exposure to the sun; but, as a general result, it was satisfactory.

In March 1855, a short length, of about one hundred feet, of Mr. De Bergue's cast-iron sleeper way, was laid down, on one of the coal sidings, at the London Goods Station. The rail used was a flat-bottomed T rail, about 60 lbs. to the yard. It was fixed to the sleeper-plates, in a small dovetail groove, cast on one side of the plate; the other side of the rail being clipped by a small wedge-shaped casting, through which was passed a vertical eye-bolt, for holding down the rails, and securing the tie-bars. The sleeper-plates were 18 inches long, by 14 inches broad, and were laid at intervals of 2 feet from centre to centre. The upper surface of the plates was intersected by vertical ribs, crossing each other, and on these the rails rested. The thickness of the plates was about $\frac{1}{4}$ of an inch throughout. It was said, that a difficulty was experienced in the cooling of the castings, and to meet this, Mr. De Bergue invented an ingenious method of annealing them, and a certain apparatus for facilitating the moulding. The rail-ends were jointed with ordinary wrought-iron fish-plates and bolts. The system, as remarked by Mr. Adams, was an ingenious contrivance for diminishing the weight of metal; but in this instance the parts were evidently too weak, as was proved by the result of the trial. When taken up, after 18 months' wear, about 20 per cent. of the sleepers were found to be broken; some of them longi-

tudinally, some transversely; and there was no doubt, that had they been laid in hard shingly ballast, instead of in burnt clay, a much larger proportion would have been broken, especially if subjected to high rates of speed. Mr. De Bergue doubtless arrived at the same conclusion, and prudently increased the strength of those afterwards laid down on the South-Western Railway, by which means they might be made to bear the traffic. It was shown, by the trial on the Great Northern Railway, that the plate-sleepers required a less amount of attention, in the way of packing and lifting, than the ordinary transverse wooden sleepers. This might, in a great measure, be attributed to the fact of the plate-sleepers having but little tendency to partake of the rocking motion, which was one of the great sources of disturbance on the transverse sleeper system. One of the chief defects of the system was the method of fixing the rail to the sleeper, for if the small dovetail lip of the casting, which confined the foot of the rail, should break, or the holding-down bolt be neglected by the plate-layers when it became loose, it was obviously unsafe, as the outward thrust of the wheel would act with a considerable amount of leverage on the rail, and the hammering thus produced would have a tendency to break the sleeper. In point of economy, or first outlay, this system might have its advantages, and, with some modifications, it would doubtless answer well for light traffic, in certain situations.

In November 1855, an experiment was tried, on the Great Northern Railway, with Mr. Adams' "suspended girder rail." A short length was laid on the up-line, near the junction of the goods and coal sidings, south of Copenhagen Tunnel, where the gradient was 1 in 100. The rail was of the double-headed section, $1\frac{3}{4}$ inch wide on the tread, presenting an unusually small amount of bearing surface to the wheel. When laid in place, with the wing-plates, it formed a compound rail and longitudinal sleeper, about 13 inches wide, with a vertical web 7 inches deep. The result of the trial had, in some respects, been highly satisfactory, though the system perhaps had some defects. It possessed the great advantage of being nearly equally rigid in all its parts, and there was a certain amount of elasticity, derived from the springing of the wings, and a very slight amount of longitudinal deflection. In travelling over it, the difference in the smoothness of the way, as compared with the transverse sleeper system, was very perceptible. The sleeper-bed being very near the surface of the rail, was found to afford great facilities for packing, as there was no necessity for opening the ballast. It was easily lifted, with an ordinary lever, when the ballast was beaten up in the usual manner. A road laid in this way was lifted in less than half the time

required by the wood-sleeper system. The sample on the Great Northern Railway was laid down under somewhat unfavourable circumstances, as there was a dressing of only about 6 inches of good clean gravel, while the lower ballast was composed of burnt clay, in a very soft and wet condition. Some objection to the system might perhaps be urged, on account of the difficulty in replacing the rails when worn out, as the cross-bolts lay beneath the wings, and a rail could only be replaced by opening out the ballast. The break-joint in the plates also increased the difficulty of removal. These defects might, however, be much lessened, by the introduction of a proper box-spanner, for reaching the bolts. No difficulty was experienced in laying the road. The parts being bolted together in lengths, upside down, were then turned over, and the different sections, when brought end to end, were bolted together from below. The wing-plates, as at present constructed, were perhaps ill adapted for laying in station curves, as they could not be bent with the ordinary screw-press used by the plate-layers. The plates would, however, answer every purpose, if made in short lengths—say of 2 feet, or 3 feet—for sharp curves; or longer wing-plates might, possibly, be purposely bent, in the hot state, when leaving the rolls. The rails themselves were easily bent. The sample laid down on the Great Northern Railway was placed on a curve, and did not present so nice an appearance to the eye as it would have done had the plates been properly prepared. Mr. Burleigh considered, also, that the tread of the rail was too narrow—an evil easily remedied, but one which had doubtless caused much of the deterioration of the rail, though it should be remarked, that these rails had lasted longer than others of the ordinary section adjoining them.

With regard to the statement, that a great number of the bolts applied to the brackets used on wood sleepers had become loose, it should be observed, that those identical bolts were made too large for the holes, and the bolts had the worm of the screw partly shorn off in the driving, which would quite account for all the defects that had been spoken of.

Mr. W. H. BARLOW said, that as there were more than eight hundred miles of single line laid with the "saddle-back rail," it must speak for itself. If it was an advantageous construction, it would continue to be used, but if other systems were found to be better, they would supplant it. He wished, however, to correct a statement which had been made, that wooden sleepers were finally adopted in laying this rail. Mr. Barlow had laid a few miles in this way, and, he believed, Mr. Ashcroft had also done so. But the latest, and what appeared to him the best, samples of this road were laid without sleepers. There were two difficulties which

stood in the way of this description of road: the difficulty of manufacturing a sound rail of that form, and the rigidity of the road when made.

The wrought-iron road was more rigid than that of cast-iron. There were nearly thirty miles of double line, of cast-iron road on the Midland Line. Between Leeds and Bradford the whole of one line, as well as a portion of the other, was laid with cast-iron sleepers. This had been done about five years, and had to sustain a very heavy traffic. It was laid in ash ballast, and the condition of the road was good in every respect. He had observed, that where cast-iron sleepers were laid in gravel, or sand ballast, a sensation of rigidity was felt. At first, when the rails were new, nothing could run better; but as the wear of the rail went on, the unevenness of the surface produced this effect of rigidity. He believed that effect might be remedied, and he looked to the sleeper of Mr. Samuel, in which the rail was held by means of wooden cushions, or a sleeper constructed on that principle, as the proper remedy. The elasticity attained by the wood, so employed, would, he believed, from recent experiments, remove the only remaining objection to the employment of iron in the substructure of permanent way.

Looking at the question generally, he thought, that as more than a thousand miles of single line of iron road were laid and in operation, enough had been done to show the practicability of using that material. They might not have got the right construction, but he felt confident that iron was the right material. In fact, it did appear to him absurd, in a country abounding in iron, that there should be spent, annually, hundreds of thousands of pounds, in bringing timber from foreign countries, to lie and rot in the railways.

With regard to the difficulty of keeping the bolts and nuts tight on fish-jointed roads, he must say, that he had used fish-joints on more than three hundred miles of double line on the Midland Railway, and though he could not say there were no loose bolts, yet the difficulty experienced in this respect was very little, when ordinary care was bestowed. Of this length, about fifty miles were fitted with the supported fish, and two hundred and fifty miles with the suspended fish. The suspended fish-joint had proved the best, and that was the mode at present used throughout the line.

Mr. ERRINGTON observed, that about a quarter of a mile of double way had been laid with Mr. Adams' open bracket chairs, on the South-Western Railway, at Putney, in a rather unfavourable position. From a recent examination of this road, he could state, that the bolts were fast, and the road itself was in excellent order. At first, four, or five of the brackets broke within two, or three days, and caused some misgivings as to that particular

form of chair. But, subsequently, the results had fully satisfied all their anticipations, and not the slightest casualty had since occurred, during the twelve months the way had been laid. The Inspector on that part of the line, told him that not more than three, or four bolts had required to be replaced during the last three months. In fact, he could not desire to see a better road than that at Putney. A little nearer to London, on the same line, a new form of this bracket-chair had been tried, for the last ten months. It had a piece underlapping the rail, like the bottom of an ordinary chair; but the result was not quite so satisfactory as in the other case. At Kingston the result was more favourable. There was but little destruction of bolts and nuts, and the fastenings were all quite tight; these facts were not consistent with some of the statements which had been made.

On the same railway, the "fish-joint" had been partially used for about three years. In the first eighteen months, they experienced considerable difficulty, but now the road was in good condition, and not more than one bolt in fifty was in the slightest degree loose. The wear of the rails, particularly at the joints, appeared to be less at those parts of the line where the "fish" had been used, than at other places, where the ordinary system had been followed. He might remark, that at the first introduction of "fishes," the plate-layers were not accustomed to bolts and nuts, and therefore it was not surprising, that there was a want of expertness and success in their use, which practice would remove. In this case, at the end of three years, it was found quite easy to maintain a road in a good, serviceable condition, with their aid.

He had also tried on the South-Western, at the same time, and near the same place, as the bracket-chairs were laid, some of Mr. De Bergue's cast-iron plate sleepers. There was no lamination of the rails, which were only 58 lbs. per yard, and he had found that the upper surface was less injured, and there was less difficulty in keeping the road in order, than with rails weighing 80 lbs. per yard, laid on cross-timber sleepers; as in the latter case the rails were stripped and much injured.

With regard to the remark, that the double-headed rail could not be turned, because the chairs indented the lower table, his experience led him to an entirely different conclusion. He found it used almost everywhere in that way, without the slightest difficulty, and few, if any, rails of that description were finally rejected, as being worn out, before they had been reversed in the chairs; on the South-Western Railway the plan of reversing the rails had been followed with great advantage. On that line the original rails weighed 75 lbs. to the yard, and the bearings were 5 feet apart. A considerable portion of the original road, which had been laid sixteen years, was still in existence, and was in a very

good condition, notwithstanding that the weight of the engines and of the trains, as well as the speed, had been much increased in the interval. In fact, the joint was the main thing to be attended to. There was such a thing as too great strength, or rather rigidity, in a permanent way, in which case the iron was crushed; and he doubted whether rails 80 lbs., or 90 lbs. to the yard were more efficient than those of 75 lbs. to the yard.

Mr. C. MAY could confirm several of the statements made by Mr. Errington, with regard to the South-Western Railway. When "fish plates" were first tried on that line, it was only as a small experiment, so small, indeed, that it was not deemed necessary to prepare rolls purposely to roll the "fish plates," so as to fit the rails, and the bolts supplied were of a very inferior character. The rails used had also lain by for a long time, had become rusty and scaled very much. He was happy to hear, however, that the experiment, in spite of these disadvantages, had succeeded, and with a trial under better conditions they might look for more favourable results.

He thought that the matter of the first Paper did not accord with its title, and that it did not give a correct representation of the state of this question at the present time. It omitted to notice, that which formed a large part of the general system of permanent way throughout this kingdom; for instance, the continuous bridge rail of Mr. Brunel was not mentioned in such a way as to give an idea of the extent to which that rail was used, what was its proportionate adoption, compared with the whole of the lines in operation, and what were its merits. There was little notice of the ordinary double-headed rail, and its usual application in chairs; but he found a passage, in which it was stated, "The rail is placed in the chair on a slope, and is only kept up by the keys." Now, nothing could be more remote from the fact than that. In the ordinary chair the rails rested on a curve in the chair. The rails were keyed in fast by the wooden keys, and he did not think they received any material support from the keys, further than being kept in their place. The wooden keys were, he believed, first introduced by Mr. Locke, M.P., V.P. They were afterwards improved by himself, by the introduction of the system of continued compression, in a heated state; and he calculated, that they had been used on six thousand miles of railway. Yet there was no notice in the Paper of the general adoption of that system. Again, it was stated, that the seat of the chair was about 2 inches above the sleeper, whereas the customary thickness of the bottom of the chair was from $1\frac{1}{2}$ inch to $1\frac{3}{4}$ inch. The effect of the elevation of the rail, above the top of the sleeper, in producing lateral motion of the trains, and a tendency to upset the chair,

had been greatly exaggerated. In fact, he believed, no such effect took place. There were instances in which the same chairs, trenails, and keys, which had been laid down twelve years since, were now in existence and in good order. It was pure assumption, therefore, to say, that the elevation of the rail by the use of the chair produced any injurious leverage.

The "fish" joint was first introduced as a suspended joint in the year 1847. It was published as the invention of Messrs W. B. Adams and Robert Richardson, and therefore, he thought, it should have been so stated in the Paper, instead of the former gentleman claiming all the merit. Mr. May had been connected with the early experiments in fishing joints, and he confessed, that in the first instance, he formed an unfavourable opinion of the system. In matters connected with permanent way, it was peculiarly the case, that until they were subjected to the test of experience, opinions were of but little value. With regard to the assertion of the bolts working loose, he was able to say, that Mr. Henry Woodhouse, who had charge of the permanent way of the London and North-Western Railway, had stated, that he had experienced no difficulty whatever in keeping the bolts tight.

With respect to the "saddle-back rail" which had been introduced just before Mr. Adams' former Paper was read, in 1852,[1] it was objected, that it would not answer, because the ballast could not be packed up within the hollow, and that, therefore, it would not have the whole bearing due to its width. Now, Mr. Brunel, V.P., had most satisfactorily answered this point at the time.[2] He said, "It was presumed, that the saddle-back rail did not take a solid bearing on the ballast, in consequence of the difficulty of packing it; now it was well ascertained, that ballast of almost any kind became, in time, so perfectly rammed into the cavity, that a nearly solid mass was formed, whereon the spreading flanches took a solid bearing, at a sufficient depth to receive the necessary lateral support, without that hindrance to perfect drainage which would be likely to occur from an extreme depth of web, unless there was such a thickness of ballast as would be very expensive in practice."

The results of actual practice since that period had shown that this opinion was perfectly correct; no difficulty had been experienced in packing the ballast, so as to retain its proper position in supporting the rail. Moreover, several French engineers had adopted the saddle-back rail, and were so satisfied with it, that

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., pp. 244–273.
[2] Ibid., p. 276.

they now proposed to use it still more extensively. Already there were about nine hundred miles, of single line, laid upon this system. It was true, there had been partial failures, but he believed they were not of such a nature as would warrant the entire rejection of the system, without further trials. Some of these failures might, perhaps, be accounted for, by imperfect manufacture—whole strips of the surface had peeled off from that circumstance—and there had been some difficulty with the joints. But all new inventions had to pass through a considerable number of, what might be called, failures, and experience must be gained, before the final result could be attained. He remarked that in drawing up specifications of rails, it was usual to specify a certain amount of, what was supposed to be, superior quality of iron for the wearing part of the rail; now, it was questionable, if this was really superior for the purpose. In the saddle-back rail, whole strips had come off, as he had stated; and an experiment, in which such rails were planed down to the inferior iron, seemed to show, that the iron which had received less working in manufacture, wore better than that which was supposed to be superior metal; he considered that the rails should be more homogeneous than they were at present.

Mr. BRUFF said, no allusion had been made to the importance of fixing the chair permanently to the sleeper, which was quite as essential as fixing the rail in the chair itself. He felt bound to say, the system of Messrs. Ransome and May—that of chilled chairs with compressed keys and trenails—formed a very good joint fastening: in fact, he believed, if that system had been more generally used, it would have prevented the introduction of many useless inventions, and would have insured greater safety in travelling. On the Eastern Counties lines, which were about five hundred and sixty miles in length, they had nearly every variety of permanent way, that had been prominently alluded to, in the course of the discussion. The saddle-back rail upon sleepers, of which they had a short length, made a fair road, and was easily maintained; there was also a considerable length laid with Mr. Samuel's fish chair, and he must say, that, as far as his observation extended, it made the best road on the Eastern Counties lines. It might not be the best plan, but, in this case, the Company had the advantage of using good materials—new rails, plates, chairs, and sleepers; while the "fish-joint" system had been generally applied to old rails, which were very much worn, particularly at their ends; it had been used, indeed, more to give assistance to the rails, than for making the most perfect road. The result had been that the half-worn rails, having so much strain thrown on their ends, after a short time stripped in their top table. He had also found, that the "fish-joint" system could

not be so usefully applied with the single-faced as with the double-faced rail; and had observed many more failures with the former, than with the latter. With regard to the question of loose bolts and nuts, he was convinced that, if engineers were disposed to pay a proper price for those articles, there would not be any necessity to complain of them. But it was too much the custom to take that which was cheapest, without regard to the quality of the material. He had been obliged to substitute large quantities of new bolts and nuts over one hundred miles of railway, entirely on account of faulty manufacture in the first instance; while upon thirty miles of line, for some time after it was fished, it cost nearly as much to keep the bolts and nuts tight, as it had done to maintain the road before it was fished.

With reference to the "fish-joint," he believed, that Mr. Adams had nothing whatever to do with the invention, beyond giving it a name. The invention, as patented, was taken by Mr. Richardson to Mr. Adams, who had the far-sightedness to perceive that it would become valuable. At the same time, he felt it incumbent on him to state, that the fish-joint was laid down by himself prior to that period, whilst Mr. Richardson was his Assistant, in order to overcome a difficulty. A timber bridge, of about 50 feet opening, was considered too weak for a locomotive to run over it safely, at high speeds. After some consideration, it occurred to him, that the simplest mode of imparting strength, was to connect, or "fish" the rails, thereby converting them into a tension bar across the bridge. That had the effect of rendering it temporarily safe, until a stronger structure could be erected, and as far as he knew, that was the first application of the "fish-joint" to the railway system. Mr. Richardson improved upon the idea, and then went to Mr. Adams, and conjointly they brought it to its present state. He had subsequently applied it, in a similar manner, to impart rigidity to timber bridges.

Before concluding, he would observe that, about three years since, there had been a discussion at the Institution[1] on the same subject, in which he took part; when the question was raised as to the proper weight and strength to be given to rails. The general opinion, at that time, ran strongly in favour of heavy rails of from 90 lbs. to 100 lbs. per yard. Upon the Eastern Counties lines, he had found, that the heaviest rails made the worst road, were less durable, and, in course of time, became the most dangerous. Upon that line, where rails of 95 lbs. to the yard had been used, they had more breakages than with any other. Those were now being replaced with rails of 75 lbs. per yard, accurately "fished," which, compared with the cost of renewing with heavy

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xi., pp. 473–477.

rails, would effect a considerable saving; and he was certain it would make a better, safer, and more durable permanent way.

Mr. HAWKSHAW, V. P., objected to the system of endeavouring to prove the value of one particular invention, by depreciating all other attempts at improvement. He thought credit ought to be given to Civil Engineers, for inquiring into the merits of the particular forms of rail, chair, or key, submitted to them; and that there was no necessity for wholesale denunciations of all the other systems to support that advocated at the moment. The consequence of this practice was, that in discussions on permanent way, there occurred a series of contradictions, which might lead to the assumption, that nobody had ever constructed a railway fit to be used, and, in fact, that engineers had yet, in this respect, to learn their business. He had used most of the well-known systems of permanent way, and he would say of them, generally, that nearly all would make a good road if properly treated. He had a length of road laid with Mr. Greaves' spheroidal iron sleepers, which had been in operation seven, or eight years, and made a good road. He should have no hesitation, were he disposed to change the system he was then adopting, in laying down those sleepers, being quite certain that a good road could be made on that system. He had also used fish chairs, and thought both Mr. Samuel's and Mr. Barningham's helped to make an excellent road. He had used the double-headed rail, the bridge rail, and the contractor's form of rail; and had laid almost as much road upon longitudinal timbers as upon cross sleepers. Each was good if executed in a proper way, and there was scarcely a choice between them. He had also used extensively Messrs. Ransome and May's compressed keys and trenails, and during a period of more than ten years, no renewal of those fastenings had been required. With regard to bolts and nuts, if engineers were desirous of using them, and paid a proper price for them, they could be made to hold fast. For commercial reasons, engineers could not exceed a certain amount of expenditure; the cost of roads whether for the pack-horse or the locomotive, must bear some relation to traffic, and the times of their construction; but he had no hesitation in saying, that if an engineer was instructed to make the best permanent way he could devise, without regard to cost, he could make a very superior road to any now laid down, on almost any of the systems that had been brought forward.

He wished to say a few words on the subject of patents, which had been so much discussed. He was not one of those who objected to an inventor taking out a patent; he had as much right to it as the author of a book had to his copyright. He believed it did good, inasmuch as many minds were occupied in seeking after improvements, which would not be so occupied, but for the

power of securing the advantage of the protection of a patent. Many persons invented, but had not the means of carrying out their inventions, and he saw no objection, generally, to persons with the requisite business habits, being associated with inventors, to work their patents, but there were certain combinations of this kind which he thought it desirable to avoid. He spoke now in the interest of the profession. He considered it was objectionable, that engineers largely concerned in the making and maintenance of railways, and having the charge of important lines, should themselves unite to buy up patent rights, for every form of rail, chair, sleeper, and fastening, and to bargain with the various Railway Companies for the use of these patented inventions. This system, he felt, was now operating in a manner, and to an extent, which the framers of it never contemplated. He had found it necessary, latterly, in making out specifications for permanent way material, to place upon the party supplying them, the liability of all charges, in respect of patent rights. He had, in some cases, when consulted by the manufacturers, told them, that with respect to particular patents, he did not consider the parties entitled to receive any payment. The reply of the manufacturers had been, that it was difficult for them to demur, when so many engineers were interested in enforcing the claims. He wished, therefore, that those patent rights were in the hands of commercial men only, who, he thought, would manage them in a more satisfactory manner than engineers would do.

Mr. P. W. Barlow said, the observations which had been made with regard to the disadvantages of a number of individuals, whether engineers, or commercial men, holding patents called for a few remarks. He thought it would be admitted, that engineers, generally, had some difficulty in dealing with patentees. Now, when the multiplicity of inventions relating to permanent way was taken into consideration, he believed the effect of an association which should hold all, or nearly all, such patents, would be to relieve engineers of a great difficulty, because the patents on this subject being so numerous, it was almost impracticable to deal with each patentee separately. He happened to be a leading member of a Company of the kind, and he would state how it originated. In 1849, before any change had been made in the ordinary construction of permanent way, several engineers of railways became sensible of two great imperfections in the old system,—the destruction of the joints of the rails, and injury to the rolling stock, by the hammering action in the ordinary chair. The cost of renewal arising from the rapid decay of timber sleepers was also very great. Patents were then taken out, for inventions to obviate these defects. It was subsequently suggested, by the mutual friends of the two parties, that greater advantages would

be probably attained by co-operation than by acting separately. He must confess that he did not think such a course unprofessional; but he considered that it was not to the interest of engineers of railways to take out patents.

Mr. SOWERBY observed, that in determining the system of permanent way to be adopted upon the Indian Railways, it was desirable that it should be as free from complication as possible, so that it might be readily laid by native workmen. The weight of the rails was also an important consideration, as affecting the question of freight. He considered those best adapted for the purpose, which approached, most closely, to the common contractor's rail. They were easily laid down, and could be made very light. The expense of shipping rails from this country was so heavy, that the question of manufacturing them in India had been discussed. They were not, however, at present, able to manufacture bar iron. Mr. Sowerby had, therefore, suggested the use of cast iron. The peculiar character of Indian iron, from the fact of its being made with charcoal, rendered it very good for that purpose. It was the opinion of many engineers, that timber was liable to be destroyed in India by the white ants. His experience went to show, that this was a fallacy. He had seen timber structures, which had been erected for many years, and were scarcely affected by that cause. It had been found, that the white ants would not remain in spots where they would be subject to constant disturbance, as by the noise and blows of a passing railway train. The permanent way need not, therefore, be wholly of iron, as was at first considered necessary.

Mr. W. POLE stated, that the permanent way of the East Indian and the Madras lines, which he had superintended for the late Mr. Rendel, was composed of double-headed rails fixed in chairs in the ordinary way, with compressed wood keys, and fastened by compressed trenails to cross timber-sleepers, and with fish-joints. The rails were rather heavy; 82 lbs. per yard—but that weight had been adopted with the concurrence of the authorities of the East India Company, who wished to have a durable permanent way, to provide for the heavy traffic which it was believed would eventually come upon the line.

As trenails had been alluded to, he would mention an improvement he had lately introduced on those lines. The objection made to wooden trenails was, that they were sometimes sheared off, on sharp curves, or crossings, from the sudden lateral blow of the engine-wheels. In the ordinary way of making trenail holes, a sharp edge, or "fin" was left, which had a tendency to aid in this shearing effect, as well as to damage the trenail whilst it was being driven. The improvement made was in slightly countersinking, or coning out, the bottom side of the hole, by

which the fin was removed, and the fastening was much strengthened, as the result of trials had conclusively shown.

The fish-joint system had been adopted on the Indian lines to a considerable extent, and as it was believed that its success depended, in a great measure, on the care and accuracy with which the joint was made, considerable pains had been taken to render it as perfect as possible. He considered it might be useful to state, the principal points to which attention had been directed. In the first place, the surfaces of bearing between the fish and the rail should fit perfectly, and should be straight on the section. It was a common practice to make them of a curved, or ogee shape, but this was injudicious, for wherever slight inaccuracies occurred in the rolling of either the fish, or the rail, they would not fit; but if straight inclined lines were adopted, they would allow for considerable variation, without detriment to the adjustment. The angle of inclination of these lines was also of some importance, and exercised considerable influence on the amount of strain on the bolts. The fish-plate should, in its normal condition, leave some space between its inner surface and that of the vertical web of the rail, so as to allow for accidental variations in size, or shape, without permitting the fish-plate to bed up against the web, and lose its proper bearing against the top and bottom flanches, which it was highly important, under all circumstances, to preserve. It was further essential, that the fish-plates should be quite straight and true in form, and free from "winding." The holes, both in the fishes and rails, should be of ample size to prevent the bolts from binding within them; they were frequently made too small in the vertical direction; they should be at right angles through the web of the rail and the fish-plates, and perfectly accurate in position. The bolts and nuts should be forged true, particularly as regarded the faces of the heads and nuts, which should be accurately square with the axis. The thread should be brought well up, and the nuts should fit so tight, as not to be moveable without a spanner. If these precautions were attended to, the fish-joint would be found to answer well, and to give little trouble in use. It was of course necessary, that the manufacture of all the parts should be rigidly supervised, or the required conditions could not be insured; but he had always found that with respectable manufacturers, a judicious system of inspection, so managed as to be careful in essential points without unnecessary severity, would succeed in obtaining the correctness desired.

Mr. Pole had lately tried a plan of tapping one of the fishes, either instead of a nut, or with the addition of a nut, as a lock; this appeared to answer well in the cases where it had been laid down, and offered some advantages of importance.

Mr. G. P. BIDDER, V.P., said, he could not imagine any difficulty in making a good permanent way with rails of 70 lbs. or 75 lbs. to the yard, sleepers 3 feet apart, and chairs of 25 lbs., or 30 lbs. in weight. This system had been found to be capable of adoption in Egypt and in the Crimea. In the former country Mr. Greaves' spheroidal cast-iron sleepers had been used with great success. In Norway and Denmark, Canada and portions of the United States, cast-iron chairs were inadmissible, owing to the severity of the climate. In Norway he had laid bridge rails upon longitudinal sleepers, and these again on cross sleepers: in this case it must be remembered, that during six, or seven months in the year, it was impossible to open the ground for the purposes of repairs. In Canada the contractors' rail was extensively used, and the road was laid with a bountiful supply of sleepers. At the joints a plan had been adopted which had been found to answer well in the United States, and which he had used in Denmark. A simple wrought-iron plate was laid under the joint, with one edge turned over one of the flanges of the rail, and spikes were carried through the rail and plate, down into the timber. The fish-joint was undoubtedly a valuable introduction, more particularly for repairing and maintaining a line of railway that had been much worn; and there might be some merit in the cast-iron chairs and new forms of rails that had been alluded to in the course of the discussion, but which, he thought, required the test of experience. It had been said that when a railway was flat, cast-iron rails, and a light description of locomotive might be adopted with impunity. Now all those who were acquainted with railways knew, that the question of light, or heavy engines, had very little to do with gradients, and the flattest railways had sometimes the heaviest engines.

There was certainly great simplicity in the idea of the advantages to be derived by the railway world, from concentrating all inventions for permanent way into the hands of one Company; yet, he thought, engineers, who were bound to look after the interests of the Railway Companies for whom they acted, could make a better bargain with the inventors themselves, and that they ought always to be prepared against a combination which was not for the interest of their employers, by having the means of superseding any inventions which could not be obtained on reasonable terms.

Mr. C. MAY exhibited a specimen of a bridge rail, rolled from an ingot of cast steel, made under the "Uchatius" system, of such a quality of metal that razors might be made of it. This had been accomplished by the Ebbw Vale Iron Company. He believed, that before many years, steel rails would be as cheap as iron rails were now, and that the permanent way would then deserve its name, which it was far from doing at the present time.

Mr. W. B. ADAMS said, he had been informed, that the "Mansel" pile joint had not been taken up on the South-Eastern Railway, as stated in his Paper. He would ask the Engineer of that line, what were its advantages and cost, and whether it was proposed to continue its use?

He remarked, in reply to observations of different Members, that if screw bolts were preferred to cotter bolts, or gibs and cotters, or other fastenings, for the parts of the permanent way, a simple method of preventing either the bolt-heads or nuts, from turning and getting loose, was by the use of plate wedges, as described in his Paper. Wedges and screws were merely varieties of the inclined plane, the one taking a straight path, and the other a circular path, in action. With regard to the price of bolts, a respectable manufacturer had offered to make them at £18 per ton. The motive of Mr. Adams in designating his rail a "girder," was to distinguish its power of carrying the load between more distant supports, than that of the ordinary rail. If a rail deflected vertically, it must, of course, increase the resistance to draughts, and the depth of a rail able to distribute the load over a larger space did not necessarily, if rightly constructed, increase rigidity, or lamination. The sample laid down at King's Cross, though not the most perfect specimen that could be constructed, sufficiently demonstrated the advantage of the principle. There could be no difficulty in slitting the horizontal webs of the angle brackets, so as to enable them to bend to any curve whatever. The "fish-joint" was simply proposed to amend the defects of the battered ends of existing rails, and was not contemplated by him, as the best mode of dealing with new rails. It was similar in principle to the plan pursued in mending a sprung spar at sea. It was quite true, that fished rails did not constitute perfect "beams fixed at the ends," owing to the ends resting on an unfirm fulcrum, but the fishing produced a condition analogous to that. If the distance between the piles of the original Great Western permanent way had been spanned by inflexible girders, the beam fixed at the ends would have been realised. The stripping off of the tread surface of the "saddle-back rail," which had been alluded to, might possibly be accounted for, by the up and down bend of the fibres across the rail, in connection with the rolling loads. The most probable mode of making the saddle-back rail useful, would be to insert the lower edges in a continuous flanged bottom-plate, so as to prevent the widening. It would thus be made a working rail with elastic action, but at a very heavy expense. He maintained, that the Barlow cast-iron sleepers used on the Londonderry and Enniskillen Railway were materially increased in weight and altered in form, as compared with those originally designed. Mr. Reynolds was the first to apply wood linings within cast-iron sleepers for rails to rest upon; the rail being of the bridge form.

An objection had been taken to his Paper, that it did not embrace every description of permanent way that had been introduced, nor dwell upon bridge rails, chairs, trenails, and other matters. It was impossible to comprehend in one Paper all that might be said upon the subject: and the present must be taken as a sequence to that on the same subject read in the session of 1851–2.[1] He had purposely omitted some matters dwelt upon in the previous communication. With reference to the priority of the invention of the fish-joint, he could only say, that the idea did not come to him either through Mr. Bruff, or Mr. Richardson. It was true, that the latter gentleman had informed him, that he had a plan for improving the joints of rails, and wished him to join in taking out a patent. This Mr. Adams declined, on account of the difficulty of getting a rail-patent into use. Two months afterwards Mr. Richardson came to Mr. Adams again, and informed him, that Mr. Bruff would lay down the improved joints on the Eastern Union line. Then, for the first time, Mr. Richardson explained his plan, which was a scarf-joint, of which a model was upon the table. Mr. Adams said at the time that it was not new, having been tried on the Blackwall Railway; to which Mr. Richardson replied, that his was a parallel joint, whilst that used on the Blackwall line was a diagonal joint. The operation of scarfing, Mr. Adams pointed out, took away material and strength, whilst that of the ordinary nautical plan "fishing" a spar, added both. This consideration led to the invention; and it was suggested to Mr. Richardson by Mr. Adams, was approved by him, and the English patent was taken out in the names of W. R. Adams and Robert Richardson. This patent contained the fish-joint, also the scarf-joint, and many inventions in engines, carriages, springs, and wheels. The Scotch and Irish patents which were taken out in Mr. Adams' own name alone, contained the fish-joint, but not the scarf-joint. When Mr. Adams' former Paper was under discussion in 1852, this assertion was corroborated by Mr. James Samuel in the following words:—"He gathered from the Paper, that Mr. Adams claimed the invention of the fished suspended joint; the claim was perfectly valid, and Mr. Samuel had become first connected with it, by introducing it practically on the Eastern Counties Railway."[2] After the patent was taken out, it remained in abeyance for some time, as Mr. Bruff would not lay it down on the Eastern Union. About two years after the patent was taken out, a premium was about to be offered by the Eastern Counties Board for the best joint. Mr. Adams conceived the fish-joint to be the best, and he accord-

[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. xi., pp. 244 to 273.
[2] Ibid., p. 277.

ingly directed Mr. Sinclair, his foreman, to prepare the plan, which was seen by Mr. Peter Ashcroft, who had charge of the permanent way of the Eastern Counties. This resulted in ten joints being cast and put together with bolts, and from that time the plan gradually got into use. The patent subsequently passed out of his hands, in consequence of misfortunes in business beyond his own control, and the fish-joint was now the property of the Permanent Way Company.

It was simply a question of manufacture and cost, whether bolts, or keys, were made efficient, or non-efficient. The fact that roughly-made bolts did get loose, had induced Mr. Adams to devise several methods of securing them, by keys, or by plate wedges, between adjoining bolts. He thought the concurrent testimony in favour of bolts, in the case of both brackets and fishes might be considered as having settled the question of their applicability, and that, other things being equal, the question was, which mode of fastening could be supplied at the lowest cost. The mechanical efficiency of Mr. Adams' brackets had been acknowledged as at least equal to the fish-joint, and he challenged comparison, as to cheapness in cost, with any other joint. The weight of the joint brackets was 44 lbs. per pair, or about 4 lbs. heavier than ordinary joint chairs, and the intermediates were only 11 lbs. per pair, so that the total weight per mile was about 22½ tons, showing a saving of about 20 tons of castings per mile, as compared with chairs. It was most desirable to make much squarer side channels to the rails for the fishes to lie in, in order to take the strain off the bolts, and this gave rise to the proposal to stamp the rail ends, while hot, and which had the further effect of solidifying them. Whether brackets, or fishes, were used, the same principle held good. In the suspended girder rail, the side channels were rolled square, and the bolts were not found to get loose. The effect of the bolts being set in the ballast, condensed by the pressure of the loads, also added considerably to their security. Some objection had been made, as to the difficulty of getting at the bolts. This might easily be remedied by screwing up the nut on a small cast shoe, on the edge of the bracket, so as to be always in sight, with the nut and cast shoe so formed, that a lock pin could be driven in, rendering the nut permanent in whatever position it might be placed. It had been stated that Mr. De Bergue's way, consisting of a single-headed rail, laid on flat cast-iron plates, had answered well upon the South-Western Railway. The area of bearing surface on the ballast in this case was equivalent to cross sleepers spaced 4 feet apart. This was equal to the suspended girder rail, with a continuous breadth of only 9 inches, the T angle brackets being only 3¾ inches by 3 inches. The quantities would stand thus :—

Rails . . .	100	tons.
T angle brackets .	75	„
Bolts . . .	2½	„
Cast-iron shoes .	2	„
Tie-bars . .	3½	„
Total .	183	tons.

It was evident, that this would be a structure of low cost, of great efficiency, and of sufficient elastic resilience to prevent destruction. At present prices, the cost might be taken at an average of about £9 per ton, or say £1,650 per mile of single line. Moreover the rails could be turned end for end, and upside down.

After the first meeting had assembled, a sheet of diagrams of girder rails had been suspended to the wall, bearing date November 4th, 1851, being simply, not things in use, but diagrams of a patent. The apparent object of this was to make the Members believe, that there was a want of priority in Mr. Adams' suspended girder rail. Now, as the importance of dates had been spoken of, Mr. Adams had prepared two lines of consecutive diagrams, demonstrating on one, the re-patented duplicates of his forms and plans, at a subsequent date; and, on the other, the various modes of joint fastenings of the double I rail (Plate 2). The latter commenced with the ordinary chair and wooden key, and then followed the half-chairs of Mr. John Day, dated January 22, 1835, the fish-joint as invented and specified by him in May 1847, in which the fishes were suspended between the chairs without bolts, and the subsequent bolting. Then followed, Mr. Parsons' plan, February 1849, of notching the rails into timber cross sleepers, and keying them in without either chairs, or trenails; Mr. P. W. Barlow, in June 1849, for casting chairs in two halves, the chairs embracing the lower table of the rail and bolted together below the rail, similar to the plan of Mr. Day; Mr. Samuel's fish-chair, April 1850, a chair of one jaw, with a wrought fish on the opposite side, claimed by Mr. Greaves in 1846; Mr. W. B. Adams' chair, June 1851, fitting between the two tables of the rail and bolted below; and Mr. Alexander Doull, in November 1851, a chair in two parts, made of wrought iron, embracing only the lower table of the rail, but bolted through the rail. The Pile joint and the Socket joint, of Mr. Mansel, in April 1852, were specified as peculiar "combinations," to avoid piercing holes through the rails, and permitting expansion and contraction; in the latter a short piece of rail was placed between the rail ends, forming, in fact, two joints, connected by sockets in such a way as to permit the rails to slide in and out. The bracket system of Mr. Adams, (Plate 2, Fig. 12,) February 17, 1853, in wood, cast iron, and wrought iron, served as knees to

secure the rails to the sleepers, whether of timber, or metal, the rails being either flush with, or partly sunk into the sleepers. This plan differed from the chair system of Mr. P. W. Barlow, inasmuch as it formed supports for the upper table of the rail, bolting through the rail, and bearing direct on the sleepers, like ordinary flat-footed rails; in fact it was an extended foot, or base to the double I rail, and thus lowered its total height above the sleeper. Mr. Wild, on the 15th of March, 1853, and Mr. Liddell, in 1854, patented a duplicate and a triplicate of this bracket. In 1855, Mr. Barningham patented an arrangement shown by Mr. Adams in his specification of 1853, viz. a chair in two halves, fitting between the two tables of the rail, and also below the lower table, and bolted through the rails. In 1856, Mr. Adams patented the recessed fish and bracket joint.

Mr. Adams considered, with many others, that it was not desirable that a Company, consisting of engineers holding official positions, should become possessed of all the patents referring to permanent way. Such a plan tended rather to retard than to promote progress, because the Company would naturally seek to extend the use only of those systems which they already held an interest in, to the exclusion of novelties; whilst individual inventors would not be strong enough to contend against such an organised opposition, and would, consequently, be obliged to sell their inventions to the Company, or to hold them in abeyance, which was a manifest grievance and disadvantageous to the community. It was an attempt to "hedge in the cuckoo" of monopoly. The practice of writing to Railway Companies to deter them from using new improvements by alleging them to be "infringements of some one or more patents the property of the Company," was simply a vague threat, but was at the same time an unfair proceeding. It was incumbent on them to publish an accurate list of their patents, and to point out the exact infringement, that engineers might be enabled to judge, for themselves, instead of being mystified. It was the interest both of the profession and the public to overthrow this combination by uniting against it.

Mr. GREAVES said, as had been previously remarked at the Institution, there was no novelty whatever in the fish-joint. He had seen hundreds of tons of fish-plates, at Liverpool, twenty-two years ago. Mr. D. Stevenson, in his 'Engineering of North America,' which was published in the year 1838, thus described them: "The rails used on the Camden and Amboy Railway, which is sixty-one miles in length, are parallel edge-rails, spiked to transverse sleepers of wood, and, in some places, to wood trenails driven into stone blocks. Their breadth is three and a-half inches at the base, and two and a-half at the top, and their height is four inches. They are formed in lengths of fifteen feet, and secured at the joints

by an iron plate on each side, with two screw bolts passing through the plates and rails." [1] Mr. Stevenson's remarks were accompanied by sketches.[2]

Mr. J. Locke, M.P., V.P., thought the members generally would be satisfied, that some light had been thrown, during the discussion, on the important subject of permanent way, and that their thanks were due to Mr. Adams for having brought it forward. There would always, no doubt, be a difference of opinion, as to whether, or not, it was desirable to consolidate patents, under the control of one Company; but he questioned whether that was a proper subject for discussion at the Institution. He had endeavoured to prevent the commercial part of the subject being touched upon, as it was in a scientific point of view alone, that questions should be examined and discussed at the Institution. He confessed it was difficult at all times to carry out this rule, and perhaps on no occasion more than the present, when the various claims of a numerous class of inventors were taken into consideration.

The duties which the civil engineer had to perform were of a varied character, and he might unhesitatingly confess how difficult it was to arrive at the truth in questions of this kind. After having spent nearly his whole life in the construction of railways, he still felt as much hesitation in coming to a conclusion, as to which was the best mode of permanent way, as if he had never seen a railway at all. How great then must be the difficulty, to those who were just entering the profession! In the course of the discussion young engineers had been strongly recommended to avoid taking out patents. Mr. Locke quite agreed with that advice, as he was aware, that many had lost good positions by patenting improvements, and introducing them on lines on which they were professionally engaged. He had never felt the necessity, or the desirability of taking out patents.

He had introduced wooden keys on the Liverpool and Manchester Railway, as an experiment, and preparatory to their general use on the Grand Junction Lines. These keys were similar in form to

[1] *Vide* "Sketch of the Civil Engineering of North America," by D. Stevenson. 8vo. Maps and Cuts. London, 1838. Page 247.

[2] The following is extracted from a Paper on Rail Joints read by Mr. Elwood Morris at the Franklin Institute, as reported in the "American Engineer" of July 25, 1857:—"About twenty years ago, a large portion of the trunk of the Camden and Amboy Railroad was laid with a 40-lb. rail with link plates covering the joints on the outsides only. These link plates were about 5 inches by 2½ inches by ⅝ths of an inch, secured by two ¾-inch bolts. They formed in no sense what are called fish-plates (though on a recent discussion in England they have been so called), since they added nothing to the strength of the joints and were merely employed as a 'link' to keep the rails in place lengthwise. They have not been used in relaying that railroad, but have been supplanted by the ring joint and others."—Editor.

those now in general use, and they were compressed by a hydraulic machine, but in a somewhat different manner to the plan subsequently patented by Mr. May. With regard to the double-headed rail, and the assumed advantage of being able to turn it, he would ask, whether any experienced engineer ever rejected a rail of that form on account of the facility it possessed for turning? That form had been designed by him for the Grand Junction Line in 1835, partly with that object, and he believed, that in practice, advantage was taken of it to turn the rail when considered advisable; a double-headed rail was never rejected from absolute wear, without its having been turned. He thought there was sufficient evidence to show that the double-headed rail was of some value in this respect.

Mr. H. CARR remarked, through the SECRETARY, that there was one point, with regard to permanent way, which did not appear to have received the attention it deserved, that was, the relative gauges of the line and the rolling stock. It was generally acknowledged, that the Great Western Railway was a smooth running line, as compared with most of the narrow-gauge lines. This might be attributed to the width of the base, but the feature he had alluded to might prove to be far more important. This was a matter to which he had paid some attention, whilst employed on a narrow-gauge line, in conjunction with a locomotive Superintendent who had formerly been connected with the Great Western Railway. The narrow gauge referred to was the ordinary width of 4 feet $8\frac{1}{2}$ inches; the gauge of the rolling stock, when new, was 4 feet $7\frac{7}{8}$ inches; thus there was a difference, or an allowance of $\frac{7}{8}$ inch between the gauge of the line and of the rolling stock, when both were new; but when $\frac{1}{2}$ of an inch was worn off each flange there was a difference of $1\frac{3}{8}$ of an inch. The Great Western gauge was 7 feet for the line, and 6 feet $11\frac{1}{2}$ inches for the rolling stock, leaving $\frac{1}{2}$ an inch play, when new; or little more than half that before stated. Theoretically there should be no play, and practically as little as would allow for unavoidable irregularities. The play allowed on narrow-gauge lines might clearly be reduced to the same as on the broad gauge, or nearly one-half what it was at present. In order to show that this might safely be done, it was only necessary to refer to the practice of most plate-layers, in laying down switches and crossings. Crossings, more particularly, were laid on what was called tight gauge, frequently 4 feet 8 inches instead of 4 feet $8\frac{1}{2}$ inches. It was a fact, that large and varied traffic did run with perfect safety over crossings so laid down, and the general observation of plate-layers, and other advocates of tight gauge for crossings, was that "it steadied the train over them." The assertion was perfectly correct, and all that was wanted was to carry out the idea and to "steady the train" for the whole

length of the line, by reducing the play allowed between the gauge of the line, and that of the rolling stock. If any one required to be convinced of the necessity of some alteration, and the importance of some improvement, in the running of heavy traffic, let him ride on the tender of a loaded coal-train, carefully watching the action of the trucks as they ran, loosely coupled. He would notice, that instead of having a smooth rolling motion, each truck advanced in a series of oscillations, varying in intensity with the velocity of the train. Every one was aware, that trucks oscillated from side to side, but the full force and regularity of this action was only to be appreciated by watching the whole length of a loaded coal-train, or other similar train, with a clear view from end to end. If a train was designed for the purpose of destroying permanent way, it could hardly be better arranged, than a loosely coupled coal-train, with plenty of play in the gauge, to be run at the ordinary speeds of 35 to 40 miles an hour, which was not an unusual rate down inclines. Spring buffers, tight coupling, and tight gauge, the two latter carried to the utmost practicable limits, would without doubt effect a considerable saving in the maintenance of permanent way, the destruction of which did not so much arise from the fair wear of the rolling motion, as from the irregularities in the running, and the consequent violent and continuous blows struck by the wheels. As stated on a former occasion at the Institution, the labour of maintenance of an up-line with a heavy coal traffic, was found to be to the maintenance of the down line as 2 to 1, the gross weight carried over being as $1\frac{3}{4}$ to 1, the cost of maintenance increasing 25 per cent. more than the weight carried. This question of half an inch in the gauge, and the matter of tight coupling, might appear to be a trifle, but the expenditure of many thousands per annum was believed to be involved. It was as important to obviate the destructive influence of the motion of trains, as to improve the permanent way, or perhaps more so, inasmuch as to get rid of, or to diminish the wear and tear caused by the trains, was better than to add to the strength of the road.

Mr. T. R. CRAMPTON observed, through the SECRETARY, that he had practically used Mr. Parsons' chairs, and had carefully watched their working, for a considerable time; he thought it right therefore to state the result of his experience, which was very favourable as to the practical value of the system. The long chair made a joint quite equal to the best fish-joint, in point of evenness and smoothness, and superior to it in many other respects. He was satisfied, that it was more durable, did not require anything like the care and attention, and the method of tightening, by the hammer and iron wedge, was preferable to the use of the spanner with bolts and nuts. Its first cost was not so

great, and it was also much less expensive to renew, as the only parts that could decay were the end-grain wood-cushions, the cost of replacing which was trifling. He had made numerous examinations of these chairs on the Great Northern Railway, both after wet and dry weather, and always found the fastenings perfectly tight; in fact the state of the atmosphere did not appear to have any important influence on them. A considerable length of temporary way was laid with these chairs on the East Kent Railway, and although the keys were only driven half through, not one key had been accidentally loosened, or worked out. The alteration in the direction of the grain of the wood, so as to make it take the pressure endways, instead of sideways, as in ordinary wooden keys, was one of those simple, but at the same time practical, improvements, which was likely to prove of considerable value. He believed it would be found particularly so for the Indian and Colonial Railways, where a hot and dry atmosphere prevailed. These end-grain cushions, in combination with the jagged iron keys, left nothing to be desired, as a fastening.

Mr. J. S. PERRING said, through the SECRETARY, that as the system adopted on the East Lancashire Railway differed in many respects from any other with which he was acquainted, it might be interesting to the Institution to have a brief account of it. The joint chair rested on two sleepers, placed as near together as practicable, only sufficient space being allowed between for packing. The principal casting of the joint chair, by which the weight was borne, weighed 88 lbs., and the side plate 33 lbs. The use of the latter was to clip the ends of the rails, by means of two bolts, each 1 inch in diameter, below, and to keep them up to the outside cheek of the chair. The rails were also retained in their places, when the pressure was on them, by the action of small inclined planes, at each end of the chair. A small bolt, $\frac{5}{8}$ths of an inch in diameter, was passed through the chair and the ends of the rail, to prevent the rails from driving forwards, in such places on the line where the breaks of the train were generally applied. The nuts were fixed into recesses cast on the chair, and the bolts were turned in screwing up; this effectually prevented the nuts from shaking loose.

In another form of chair, used principally on timber viaducts, a single trough-shaped casting, with a flat bottom, was used. The rail fitted one side of the trough, and was kept in place by a "fish-plate," set up against it on the other side, by the end of a set-screw passing through a plug-nut, this latter fitting a recess in the casting. This plug-nut and set-screw had proved so satisfactory, that their use had lately been extended with success to fixing the rails of points, crossings, and checks into their respective chairs. This peculiar form of joint chair had been used for planked

bridges and viaducts. In cases where the planking was thin, and ran transversely, a number of these chairs were introduced along the whole length of the rail, in order to obtain an increased bearing surface, and distribute the weight over every plank equally. The intermediate chairs were constructed with an outside cheek fitting up to the rail, while an inclined plane, on the inside, prevented any movement of the rail inwards. So long as the joint chair kept the ends of the rail firmly in position, no key was required for the intermediates, and those that had been down for the last three years without a key, showed that there was no tendency either to upset, or for the rail to get out of place.

In sharp curves an iron drop key was occasionally used for the middle chair of each length, and as it gave an appearance of security, and was not expensive to maintain, its adoption might be extended.

This iron drop piece, or key, weighed 2½ lbs., and was found to keep well in its place by its own gravity. It would thus be seen, that the use of wooden keys was abandoned. When wooden keys were placed outside the rail, Mr. Perring considered, not only that the cost of maintenance was excessive, but also that they led to many accidents; if placed inside there was so little strain upon them that they were scarcely of any use.

In designing this permanent way the following objects had been kept in view:—1st. To obtain a well-supported, good joint, of somewhat greater strength than the other parts of the rail, and thus to avoid destructive action. 2nd. To dispense with the use of wooden keys. 3rd. To allow any rail to be taken out, with the same ease as in the old road, and without unspiking the chairs from the sleepers. 4th. To allow the use of rails of any length, without having to drill for special closures, or insides of curves.

In using cast iron for joints, it was of course necessary to have a good quality of iron and a good fit, both of which had been too much neglected in chair castings. The questions of the proper depth of ballast, and also its quality and drainage, were most important, particularly in those parts of the country where the rainfall exceeded 60 inches annually. Too much attention could not be paid to the quality of the workmanship in every part of a permanent way; the neglect of this precaution led to rapid destruction of the materials composing it, and greatly increased the cost of renewal and of maintenance.

February 10, 1857.

JOSEPH LOCKE, M.P., Vice-President,
in the Chair.

THE discussion upon the Papers No. 947, "The Varieties of Permanent Way practically used, or tried, on Railways," by Mr. W. B. Adams, and No. 959, "On some Recent Improvements in Permanent Way," by Mr. P. M. Parsons, was continued throughout the Meeting, to the exclusion of any other subject.

HURRY'S RAILWAY CROSSING.

After the Meeting, a Model of an Improved Railway Crossing, by Mr. Henry C. Hurry, was exhibited in the Library.

The object sought to be attained was, to make a perfect continuity of the main line rail through all crossings, without "point and wing" (or "elbow") rails, so as to avoid the extra wear and tear which at present took place at crossings, both to the permanent way, and to the rolling stock, and the danger of wheels getting off the rail, or on to the wrong rail.

The steeled "point and wing and elbow" rails used in the construction of ordinary crossings, were not used in this system, and as they involved considerable wear and expense, it was believed that a saving in this item of railway expenditure might be fairly anticipated.

In this improvement, where a main line was crossed, the rail crossing, in approaching the point of crossing, was raised about 1¼ inch above the level of the main line rail. The crossing rail, both inside and outside the main line rail, was cut at such a distance as to allow of the free passage of wheels upon the main line, and both ends of the rail were bent down for a length of about one foot, so that the extreme points were on the same level as the main line rail. Between the end of the rail and the outside of the main line rail was laid a packing, at the same level as the main line, and in the line that the flanges of wheels traversing the crossing would take, of a sufficient width to allow for deviations of gauge. Between the inside of the main line and the end of the crossing rail was placed a moveable packing, or wedge, which rested upon inclines in such a way that it might be raised to the level of the main line, or be lowered sufficiently to allow the flanges of the wheels upon the main line to run clear. This movement was produced by the action that reversed the points leading to the crossing. By these means a level and continuous way was made for the wheels

to pass along (upon their flanges) for the distance between the ends of the cut rails of the crossing line. The gauge was maintained by a check rail.

In the crossing of a siding rail with a siding rail, the moveable packing was not required, as it was not necessary to preserve the continuity of either rail. In this case both rails were cast in the same way as the crossing rail, and they were laid on the same level, their ends being curved down as before described, to the level of a packing laid $1\frac{1}{4}$ inch below their general level, and so placed as to carry the wheels, when traversing either line, over the distance between the rails, the gauge being kept by check rails.

February 17, 1857.

JOSEPH LOCKE, M.P., Vice-President, in the Chair.

The discussion upon the Papers No. 947, "The Varieties of Permanent Way practically used, or tried, on Railways," by Mr. W. B. Adams, and No. 959, "On some Recent Improvements in Permanent Way," by Mr. P. M. Parsons, was continued throughout the Meeting, to the exclusion of any other subject.

RANSOMES' AND BIDDELL'S SOLID CHILLED CROSSING.

After the Meeting, attention was directed to a Solid Chilled Crossing, recently introduced by Messrs. Ransomes, (Ipswich).

This crossing consisted, principally, of one simple casting, chilled upon all its upper wearing surfaces. From the well-known hardness, and the peculiar crystalline structure of a chilled surface, it would be obvious to all who were practically acquainted with the great durability of such surfaces, that this application of the principle could not be otherwise than good, and the actual test of such a crossing proved, that it was in every way all that could be anticipated. One such crossing had now been down nearly eighteen months, in a situation where ordinary crossings had frequently been entirely worn out in less than six weeks, whilst this crossing was still in perfect order, and showed but slight indications of wear, and there was no reason to suppose that it might not last for three, or four years longer, so that it might fairly be presumed that it would be more durable than, at least, a dozen ordinary crossings. This test crossing was not made upon the "flange bearer principle," which would probably more than double its durability. The advantages claimed were, durability, simplicity, compactness,

and non-liability to derangement in the relative position of the parts, and facility in laying down, and in carrying out the flange-bearer principle without extra cost. None of the stock rails of the line had to be bent, drilled, or cut, nor were any of them required in the manufacture of these crossings. As a necessary consequence of these advantages, there would be considerable economy.

In the manufacture of these crossings, the method generally pursued was, first, to pour into the mould suitable chilling metal, and then to complete the process with softer, or non-chilling metal. This system had been found to be very effective.

February 24, 1857.

G. P. BIDDER, Vice-President,
in the Chair.

No. 954.—"On Chain Cable and Timber Testing Machines." By THOMAS DUNN, Assoc. Inst. C.E.

IN the latter end of the year 1847, Messrs. Dunn and Co., of the Windsor Bridge Iron Works, Manchester, were applied to for their professional opinion, as to the best and cheapest form of machine for testing chain cables, required to bear strains according to the following scale :—

TABLE, showing the comparative strength of Hemp and Chain Cables, weight per fathom, proof to which Cables are tested, weight of Anchors, and Register tonnage of Vessels.

Diameter of Iron Cables.	Equal to Hemp Cables.	Weight of Chain per Fathom.	Attested Proof upon Stud Chain.	Suitable for Vessels, as under.					Crane Chain.		
				Per "Lloyd's" List.	General List.	Length of Cable.	Anchors suitable.		Equal to Hemp Cables.	Proved to Cwts.	Weight per Fathom.
							Iron Stock.	Wood Stock.			
Inches.	Inches.	lbs.	Tons. cwt. qrs.	Tons.	Tons.	Fath.			Inches.		lbs.
$\frac{3}{4}$	6	14	4 15 0	..	30	90	..	..	$4\frac{1}{2}$	65	15
$\frac{7}{8}$	$6\frac{1}{2}$	18	5 18 0	..	40	90	..	..	$4\frac{1}{2}$	80	19
1	7	23	6 15 0	50	50	90	..	..	5	100	24
$1\frac{1}{8}$	$7\frac{1}{2}$	27	8 0 0	55	60	90	..	..	6	120	30
$1\frac{1}{4}$	8	33	9 10 0	60	65	90	4	3	7	160	35
$1\frac{3}{8}$	$8\frac{1}{2}$	37	12 0 0	85	85	90	5	4	8	200	40
$1\frac{1}{2}$	9	42	13 5 0	100	105	90	6	5	$8\frac{1}{2}$	230	46
$1\frac{5}{8}$	$9\frac{1}{2}$	48	15 0 0	130	135	90	$6\frac{1}{2}$	5	9	260	56
1	$10\frac{1}{2}$	56	17 0 0	180	185	90	9	$7\frac{1}{2}$	$9\frac{1}{2}$	290	67
$1\frac{1}{16}$	11	62	19 10 2	200	205	90	11	9	10	310	74
$1\frac{1}{8}$	12	70	23 2 2	230	235	90	13	11	11	330	84
$1\frac{3}{16}$	13	78	25 10 0	250	285	100	$15\frac{1}{2}$	13	..	..	..
$1\frac{1}{4}$	14	86	29 2 2	300	350	100	17	14	..	..	..
$1\frac{5}{16}$	15	94	32 10 0	350	400	120	19	17	..	..	..
$1\frac{3}{8}$	16	105	36 0 0	400	450	120	21	18	..	..	..
$1\frac{7}{16}$	17	125	40 0 0	450	500	120	23	20	..	..	..
$1\frac{1}{2}$	$18\frac{1}{2}$	145	48 10 0	600	650	130	27	24	..	..	..
$1\frac{5}{8}$	20	165	57 10 0	700	800	140	32	28	..	..	..
$1\frac{7}{8}$	23	191	68 0 0	900	1000	140	36	32	..	..	..
2	25	217	80 0 0	1000	1200	150	48	41	..	..	..

It is stated that the Government testing machine at Woolwich Dock Yard, has cost upwards of £1,600, and the machine at the Corporation Dock Yard in Liverpool not less than £1,800,

the foundations being included in both cases. Consequently it was out of the power of chain cable makers to have such expensive machines on their own works, and the expense of proving chains in Liverpool, or in London, was so considerable, that in case of four, or five links breaking in a chain, the cost of the repairs was nearly as much as the value of the chain. It was imagined, that if the makers could get a machine fixed upon their own works, for one-eighth, or one-tenth of the usual price, this loss would be avoided, as in case of bad workmanship, the men would put in new links at once, without any great expense. An examination induced the conviction, that it was possible to simplify the construction and to reduce the cost; and the present direct-acting hydraulic machine, of simple construction and effective action, was designed. Its cost is about one-eighth that of the others. It can be used with greater safety to the men employed in testing the chain cables, as in both the Liverpool and the Woolwich machines, the cables are laid upon a bench, or table, raised about 3 feet high from the ground, so that the chains are liable to fly in various directions, sweeping any of the men down who stand in the way. There is introduced into the new machine, a long column, or trough, having a slot throughout its whole length, section of which is given in Fig. 1. The trough is about 30 yards long, for holding as much of the cable as is to be proved at one time. This trough is laid level with the ground, upon guntrees of wood, framed together, much the same as a lathe-bed. After the chain is in its place, a few cross bars are laid over the groove, or slot, to prevent it flying upwards. After some practice, it was found that these cross bars were unnecessary, as the chain generally broke with a spiral surge, so that it could not fly out in a straight line. The first machine made on this plan was tested in May 1848. The 'Manchester Guardian' of May 24th, 1848, describes this machine in the following terms:—"NEW MACHINE FOR TESTING CHAIN CABLES.—Mr. Thos. Dunn, of the Windsor Bridge Iron Works, has lately invented a machine for testing chain cables, which is distinguished by great simplicity in its arrangement, and by which some important objects are more completely attained, than by any previous invention. The machine has been made for the Messrs. Hingley, of the Cradley Chain Cable Works, Staffordshire, who have, in common with other chain cable manufacturers, (amongst whom there has not hitherto been any regular system of testing their cables,) suffered severely, from the breakage of their cables, when subjected to the severe test of the Liverpool machine. Mr. Dunn's machine was tried on Monday last, at the works, at Windsor Bridge, previously to its being sent to its destination, in

Fig. 1.

Section of Trough.

the presence of Mr. Fothergill, (of the firm of Roberts, Fothergill, and Dobson), Mr. Walter Mabon, of the Ardwick Iron Works; Mr. Barlow, Consulting Engineer; Mr. Booth, Manager of Messrs. Whitworth and Co.'s Works; and other engineers and machine makers. The opinion of these gentlemen was highly favourable to its merits."

Since the construction of this machine, several others have been made, and forwarded to various parts of the country. They are in successful operation at Messrs. H. Hingley and Sons, Cradley Iron Works; Mr. Tinsley, Dudley; Messrs. Melrose and Hussey, Tivedale, near Dudley; Mr. Edward Griffiths, Stourbridge; Messrs. Mitcheson, Limehouse; and the Strasburg Railway Company. Those at Messrs. Melrose and Hussey's and at Messrs. Mitcheson's can be worked either by steam power, or by hand. The others are all worked by hand. The results of some actual tests with these machines will now be recorded.

Messrs. Melrose and Hussey, of the Phœnix Works, near Dudley, tested some chains and bars before Mr. W. Fairbairn, M. Inst. C.E., F.R.S., and Mr. B. Fothergill. This machine was capable of testing to 150 tons. It had four pumps, two of $\frac{7}{8}$ths of an inch diameter; and two of 2 inches diameter. The cylinder was 11 inches in the bore, with a piston-rod of $4\frac{1}{8}$th inches diameter,—made to work by hand, or by steam power. The following are the results:

A $1\frac{1}{2}$ inch chain, with stud link, broke with 42 tons. There were no stretching tests in this experiment.

A $2\frac{1}{4}$ inch chain, without stud links, stretched $\frac{1}{16}$th inch with 30 tons, $\frac{5}{32}$ths inch with 50 tons, $\frac{1}{16}$ths inch with 60 tons, $\frac{7}{8}$ths inch with 70 tons, $1\frac{7}{32}$ths inch with 80 tons, $1\frac{7}{16}$ths inch with 90 tons, and broke at $1\frac{3}{4}$ths inch with 100 tons.

A 1 inch round bar, 10 feet in length, stretched $\frac{1}{16}$th inch with 4 tons, $\frac{1}{8}$th inch with 6 tons, $\frac{3}{16}$ths inch with 8 tons, $\frac{7}{32}$ths inch with 10 tons, 2 inches with 12 tons, $3\frac{1}{2}$ inches with 13 tons, 5 inches with $13\frac{1}{2}$ tons, $5\frac{3}{32}$ths inches with $14\frac{3}{4}$ tons, $5\frac{3}{16}$ths inches with $15\frac{1}{4}$ tons, $6\frac{5}{16}$ths inches with $15\frac{3}{16}$ths tons, $6\frac{1}{4}$ inches with 16 tons, $6\frac{9}{32}$ths inches with $16\frac{3}{4}$ tons, and $12\frac{1}{4}$ inches with $17\frac{3}{4}$ tons. The section of the iron where it broke was $1\frac{1}{8}$th inch by $\frac{3}{4}$ths of an inch double.

A 1 inch square bar, 10 feet in length, stretched $\frac{1}{8}$th of an inch with 10 tons, $1\frac{9}{16}$ths inch with 14 tons, 2 inches with 16 tons, $4\frac{7}{16}$ths inches with 18 tons, $5\frac{1}{16}$ths inches with 19 tons, $5\frac{3}{4}$ inches with 20 tons, and broke at $6\frac{1}{2}$ inches with $20\frac{1}{4}$ tons. The section of the iron where it broke was $1\frac{1}{8}$ inch by $\frac{3}{16}$ths of an inch double.

A $1\frac{1}{2}$ inch square bar, 10 feet in length, stretched $\frac{1}{8}$th of an inch with 10 tons, $\frac{5}{32}$ths inch with 18 tons, $\frac{11}{32}$ths inch with 22 tons, $\frac{13}{32}$ths inch with 26 tons, $1\frac{3}{32}$ths inch with 30 tons, $2\frac{7}{8}$ths inches with 34 tons, $4\frac{5}{16}$ths inches with 38 tons, $6\frac{5}{16}$ths inches with $40\frac{1}{2}$ tons,

$6\frac{3}{8}$ths inches with 42 tons, $6\frac{7}{16}$ths inches with $42\frac{1}{2}$ tons, $7\frac{3}{4}$ths inches with 43 tons, $7\frac{3}{8}$ths inches with $43\frac{1}{2}$ tons, and broke at 9 inches with 44 tons. The section of the iron where it broke was $1\frac{13}{16}$ths inch by $\frac{15}{16}$ths of an inch double.

A $1\frac{1}{2}$ inch round bar, 10 feet in length, stretched $\frac{1}{32}$th inch with 10 tons, $\frac{1}{8}$th inch with 16 tons, $1\frac{5}{16}$ths inch with 20 tons, and broke at $2\frac{3}{8}$ths inches with 32 tons. The section of the iron where it broke was $1\frac{3}{4}$ths inch by $\frac{15}{16}$ths of an inch double. This break occurred at one of the eye-pieces at the ends. Stronger eye-pieces having been put in, the same $1\frac{1}{2}$ inch round bar was again tried, when it stretched $\frac{3}{16}$ths of an inch with 10 tons, $\frac{1}{2}$ inch with 20 tons, $1\frac{21}{32}$ths inch with 30 tons, 4 inches with 33 tons, and broke with $34\frac{1}{2}$ tons.

A 2 inch round bar, 10 feet in length, stretched $\frac{1}{16}$th inch with 10 tons, $\frac{1}{8}$th inch with 14 tons, $\frac{5}{32}$ths inch with 18 tons, $\frac{6}{32}$ths inch with 22 tons, $\frac{7}{32}$ths inch with 26 tons, $\frac{1}{4}$th inch with 30 tons, $\frac{9}{32}$ths inch with 35 tons, $\frac{5}{16}$ths inch with 40 tons, $\frac{3}{8}$ths inch with 45 tons, and broke with 48 tons. The section of the iron where it broke was $1\frac{15}{16}$ths inch double.

A 2 inch square bar, 10 feet in length, stretched $\frac{1}{16}$th inch with 20 tons, $\frac{1}{8}$th inch with 30 tons, $\frac{1}{4}$th inch with 40 tons, $\frac{5}{16}$ths inch with 44 tons, $\frac{7}{16}$ths inch with 48 tons, 1 inch with 52 tons, and broke with 54 tons. The section of the iron where it broke was $1\frac{15}{16}$ths inch by $1\frac{5}{8}$ths inch double.

A $2\frac{1}{2}$ inch square bar, 10 feet in length, stretched $\frac{1}{16}$th inch with 30 tons, $\frac{2}{16}$ths inch with 40 tons, $\frac{1}{4}$th inch with 50 tons, $\frac{5}{16}$ths inch with 60 tons, $\frac{3}{8}$ths inch with 70 tons, $\frac{7}{8}$ths inch with 80 tons, 2 inches with 90 tons, and broke with 100 tons. The lever was just rising when the bar broke across the eye. The section of the iron where it broke was $2\frac{1}{2}$ inches by $1\frac{5}{8}$ths inch, double.

A $2\frac{1}{2}$ inch round bar, 10 feet in length, stretched $\frac{1}{8}$th inch with 10 tons, $\frac{5}{32}$ths inch with 20 tons, $\frac{7}{32}$ths inch with 30 tons, $\frac{9}{32}$ths inch with 40 tons, and broke at $\frac{3}{8}$ths inch with 44 tons. The section of the iron where it broke was $2\frac{13}{16}$ths inches by $1\frac{1}{2}$ inch, double.

One of the hand machines was exhibited at the Paris Universal Exhibition of 1855, and was used by Capt. Fowke, R.E., Secretary to the British Section, for making a series of experiments on the strength and resistance of various woods. The standard dimensions of the specimens experimented upon were 2 inches square, and from 14 inches to 16 inches in length. Capt. Fowke, in an elaborate report[1] on the results of these experiments, gives

[1] *Vide* Reports of the Paris Universal Exhibition. Part I. London, 1856.—"Results of a Series of Experiments on the Strength and Resistance of various Woods." By Captain Fowke. Pages 402 to 525.

tables of the specific gravity, the transverse breaking weights, the crushing strains in the direction of the fibre, and the transverse crushing strains. In this Report he says,[1]—"A very accurate and delicate hydraulic machine for testing the strength of materials having been placed at my disposal by Mr. Dunn, of Manchester, I commenced a series of experiments on such specimens as could be obtained from the Colonial Commissioners, which were carried on in the part of the Exhibition building devoted to machinery, during the months of July, August, and September, and of which the history and results are here given.

"The testing machine consisted of a hydraulic press with the piston-rod furnished with a cross-head, working horizontally in cast-iron guides, and having a connecting-rod attached to it reaching to the end of the guides. A small valve in the cylinder, furnished with a steelyard and moveable weight, gave the means of ascertaining to a great nicety the exact amount of pressure applied."

The following account of these experiments appeared in the 'Illustrated Times' for August 25, 1855:—

"PARIS EXHIBITION.—*Testing the strength of Materials.* In a communication received from Messrs. Varral, Middleton, and Elwell, Engineers, Paris, dated the 22nd ult., there is a description of a series of experiments tried before Lord Cowley, and some gentlemen of the British Embassy, Captain Fowke, R.E., and other Royal Commissioners, with a machine (extremely simple in construction) invented by Mr. Dunn. The first experiment was on a piece of French-grown white pine, 12 inches square and 4 feet between the supports, which deflected $2\frac{1}{2}$ inches, and broke with a strain of $42\frac{1}{2}$ tons. The tension was then tested of a bar of charcoal iron, 20 feet long, and 1 inch diameter. It broke with a strain of 26 tons, after stretching 17 inches. The third experiment was upon a chain cable, stud link, made by Mr. Tinsley, of Dudley, of the ordinary iron $1\frac{3}{8}$ths inch diameter and 20 feet long. It stretched $9\frac{1}{2}$ inches, and broke with a strain of 56 tons. The fourth experiment was upon a piece of French-grown oak, 12 inches square, and 4 feet between the supports. It deflected $5\frac{1}{2}$ inches, and broke with a strain of 54 tons. One end of this log was shaky, and gave way before the full test was upon it. After these experiments a very sound piece of French oak was selected, of the same dimensions as the other. This stood a test of 69 tons."

Previous to this machine being sent to Paris, a piece of Ame-

[1] *Vide* Reports of the Paris Universal Exhibition. Part I. London, 1856.—"Results of a Series of Experiments on the Strength and Resistance of various Woods." By Captain Fowke. Page 403.

rican red pine, 1½ inches square and 4 feet between the supports, was tested at the Windsor Bridge Iron Works. This stood a test of 44 tons, after deflecting 2¾ inches.

In March, 1855, some experiments were made, with the Liverpool Corporation testing machine, to ascertain the strength of the tension rods intended for the travelling cranes, made at the Windsor Bridge Iron Works, for Messrs. Peto, Brassey, and Co., and intended to be used in the erection of the large tubular bridge over the River St. Lawrence, on the Grand Trunk Railway of Canada. These rods were intended to bear 10 tons, and there were four sets of rods to each crane. Two sets were made over and above the quantity required for the twelve cranes, and those most likely to break were selected for the experiments. They were put together in two straight lines. The body part of the rod was 1½ inch round iron; the joint pins and nuts were made of the best double worked scrap iron, and of larger section than the body of the rods. The holes in the joints stretched to ⅛th of an inch oval, and the rod invariably broke where the different sizes of iron were connected together, which was from 10 inches to 12 inches from the joint pin.

Mr. DUNN said, the cost of one of his machines was between £200 and £300, exclusive of the foundations, which need only consist of a few balks of timber; whereas the cost of the Government and Corporation testing machines varied from £1,000 to £1,600, exclusive of the foundations.

Mr. RENNIE stated, that the introduction of chain cables, was due to the late Captain Sir Samuel Brown, R.N. The earliest machine for proving cables was that made by Mr. Rennie's firm, for Captain Brown. It was a compound lever machine, without a pump, and was still in existence at Messrs. Lenox's Works, and was an excellent machine. The cable originally made, according to Captain Brown's patent, resembled a curb-chain, with twisted links, so that it assimilated, as much as possible, both in appearance and elasticity to the usual hempen cable. It had, however, too much elasticity. Captain Brown then found it necessary to return nearly to the old form of link, by putting pointed stays between the links to keep them from collapsing, as they were apt to do when stretched. Captain Brown's partner, Mr. Brunton, substituted stays with broader bearing, between the sides of the links, and which were further extended beyond the line of horizontal tension. This was the present form of the links of chain cables, but Mr. Rennie contended that if the links were formed like the figure 8, they would be stronger, though in this form the cable would be apt to kink.

Mr. W. NAYLOR remarked, that the broken links exhibited, showed, in almost every instance, that the fractures had arisen from an imperfect union of the parts of the links in welding. He considered that sufficient force and rapidity of blows could not be obtained by hand labour, and that tilt hammers with the requisite speed had not yet been brought under control; neither had steam hammers, which were merely lifted by steam and brought down by their own gravity, sufficient speed for heavy chain making. He then described a new single, or double-acting steam hammer, which he had brought out, and which could be changed at pleasure, by merely moving a lever. Any amount of steam, from a mere breathing upon the piston to that of the full pressure of the boiler could be applied, and varied whilst the hammer was in full work. Two of these hammers were employed in the Eastern Counties shops at Stratford, and one at Norwich. They were of the 'Nasmyth' class, but contained several modifications, having reference particularly to the valve and valve gearing. The hammers were 10 cwt. each, and when worked with a length of stroke of 12 inches, and double acting, two hundred and fifty blows per minute could be obtained, or more than twice the number that an ordinary hammer lifted by steam, and falling by its own unaided gravity, would give. When required, they could be worked as

slow as other hammers. The same principle was applicable for riveting iron ships in course of construction—also boilers, tanks, wrought-iron bridges, rivet making, &c.

Mr. JAMES R. NAPIER stated, through the SECRETARY, that some calculations he had made, with a view to discover the law which regulated the size of the chain cable and the weight of anchor to the given ship, showed that

$$\tfrac{1}{8}\sqrt[3]{\text{Load displacement}}$$

gave the diameter of chain cable usually employed by steamers of the present form.

LAPHAM'S WATER REGULATOR FOR BOILERS.

After the Meeting, a model was exhibited, in the Library, of Mr. Lapham's "Method of Regulating the Height of Water in Steam Boilers." This consisted of a pipe and cylinder in communication, situated at the proper level of the water in the boiler, which were kept filled with cold water. Two pipes proceeded to the cylinder, the one from the steam portion of the boiler, and the other from the water space. When the water fell below the proper level, steam would pass through the lower, or water pipe, and expanding the water in the cylinder and pipes, would cause an expansive action against an india-rubber diaphragm, to which was attached a lever acting by cranks and levers upon the stop-cock, or valve in the feed-pipe.

March 3, 1857.

I. K. BRUNEL, Vice-President,
in the Chair.

The following Candidates were balloted for, and duly elected:—CHARLES BRUMELL and JOHN FURNESS TONE, as Members; JOSHUA FIELD, jun. Captain BEN HAY MARTINDALE, R.E., WILLIAM OWEN, GEORGE BANKS RENNIE, FREDERICK CHARLES WEBB, and THOMAS ROBERT WINDER, as Associates.

No. 962—On the Results of the Use of Clay Retorts for Gas Making."[1] By JABEZ CHURCH, Assoc. Inst., C.E.

AMONG the various improvements which have been introduced in the construction of apparatus for manufacturing coal-gas, the use of clay instead of iron for retorts is, perhaps, nearly the most important, and is thus worthy of the consideration of this Institution.

Brick and clay retorts have been tried at different periods, and with various success. In the winter of 1826, and the beginning of 1827, Broadmeadows' patent was brought into operation, by the late Mr. David Gordon, the introducer and patentee of compressed gas, and a Paper on the subject is contained in the archives of the Institution. This compressed gas was obtained from coal-gas, made at Manchester, by Mr. Alexander Gordon, M. Inst. C. E., with retorts constructed of bricks, Welsh lumps, and Stourbridge clay. Mr. A. Gordon states, that the defect of the system in question was, that, as they had to work with a very slight oscillation of the barometer, or water-gauge, by Broadmeadows' apparatus, they sometimes blew gas through the joints of the brick retorts, or ovens; whilst, at other times, the ovens inhaled atmospheric air, in consequence of the exhausting apparatus being worked too rapidly. The inhalation of atmospheric air was too important to be overlooked, and it became necessary to lay aside Broadmeadows' plan.

Mr. Grafton appears to have been the first to adopt fire clay, as a substitute for metal, in the construction of retorts; this was in the year 1820. The retort was at first of a square form, in the

[1] The discussion upon this Paper extended over portions of two evenings, but an abstract of the whole is given consecutively.

transverse section, but it was soon afterwards changed to that of a D, or oven shape, which form has ever since been adhered to, both in this country and abroad, and such retorts have been extensively employed. Mr. Clegg in his Treatise on Coal-Gas,[1] speaking of these retorts, observes, "They can be constructed either to be heated by coke ovens, or coke furnaces, or by the burning of tar: with coke ovens they are more durable." They "have great power to retain their heat, when brought to the proper temperature for decomposing the coal, and the introduction of a fresh charge is not nearly so much felt by them as by metal; this is a practical point,—one which I have been at much pains to ascertain, and which I would not state, were I not convinced of its correctness by personal observation." He further states, that "this power of retaining heat is proved by constant practice to produce 1000 cubic feet of gas per ton from the same coal more than the average of the London produce, and the consumption of fuel is not more than 22 lbs. or 23 lbs. of coke to carbonize 100 lbs. of Newcastle coal, taking the average of six months' working; it is even less with the Staffordshire or Lancashire coal. When properly constructed, these retorts are not in any degree liable to fracture, or to the escape of gas, but are of such strength as to resist the greatest pressure which is likely to be put upon them. The coke also made by them is invariably of better quality, and produces less breeze or waste." In speaking of the durability of the fire-clay retort, he says, "In some instances it has lasted for the extraordinary period of twelve years; while, during this time, at all other works where the invention is not yet used, it may be asserted that iron retorts have been renewed as many times."

In Scotland, clay retorts were adopted at a very early period, and they are now in general use there.

According to the experience of the Author, in different towns, the comparative quantities of gas made by iron and clay retorts, of the D form, and equal in size, that is, 15 inches by 13 inches on the cross section and 7 feet 6 inches in length, are as follows:—The duration of the iron retorts for 365 days, working off 1½ cwt. of coal for each charge, was equal to the carbonization of 2,190 cwt. of coal, which at 9,000 cubic feet of gas per ton, gives a total quantity of 985,500 cubic feet of gas per retort; whilst the clay retorts worked 912 days, carbonizing 5,472 cwt. of coal, which at 9000 cubic feet of gas per ton, gives 2,462,400 cubic feet of gas per retort. The clay retorts are capable of yielding a greater quantity of gas, from the same quantity of coal, than the iron retorts, but the specific gravity of the gas, so made,

[1] *Vide* "A Practical Treatise on the Manufacture and Distribution of Coal-Gas," &c. By S. Clegg, Jun. 4to. Plates. Second edition, p. 142.

is less, and its illuminating power is diminished, in consequence of the increased temperature of the clay retorts above that of the iron retorts. Such an increase of temperature, upon an almost exhausted iron retort, would cause the metal to melt, whilst the clay retort would be unaffected by the degree of heat, when the great body of gas yielded by the charge has passed off. The want of illuminating power in the last portion of gas, it is well known, is owing to the gas being decomposed by the higher temperature of the retort, when part of its carbon becomes deposited; but it is to be remembered, that when the same quantity of gas is produced from equal quantities of coal, the gas in each case will possess the same illuminating power, whether carbonized in iron, or in clay retorts.

Of the three forms of clay retorts usually employed, namely, the circular, or round, the D, or oven shape, and the elliptical, the D shape is to be preferred, because this form of retort admits of a stratum of coal being distributed of an equal thickness throughout; but the form of retort must in some cases be regulated by circumstances, and it is not unusual to have these three forms of retort placed in the same bed. The cost of setting the clay retorts is in some cases even as much as 20 per cent. less than that of iron retorts, on account of the former not requiring any tiles, or shielding, like the latter, so that there is a consequent reduction of labour and material.

In small works the clay retorts are used without an exhauster. When that machine is not used, it is necessary to work at as low a pressure as possible upon the retort; but it is found, in practice, that they may be profitably worked at a water-gauge pressure of 7 inches. Should the pressure be increased beyond this point, a perceptible leakage takes place, through the pores of the retorts, and this leakage will always be in proportion to the pressure. At an increased pressure, leakage continues for a considerable period, or until the pores of the retort become filled, by a deposition of carbon taking place within them, throughout the entire mass of the retorts; evidence of which is perceptible by breaking a retort, that has been working under the circumstances described.[1]

The most practical method of working clay retorts, in large works, is with the addition of an exhauster, the operation of which reduces the pressure on the retort, by drawing off the gas before there is time for an accumulation of pressure to take place within it. The further advantage of an exhauster is that, by taking the pressure off the retort, the quantity of gas is increased about 200 cubic feet per ton of coal, the gas not being then forced through

[1] A specimen of a broken retort was exhibited when the Paper was read.—Ed.

the fissures and pores of the retort, as when the pressure has the power of increasing in the absence of an exhauster. The same advantages would apply to small as well as to large works, by the use of an exhauster; but the expense of an exhausting apparatus, and steam machinery to work it, would not in the former case be compensated by the gas saved.

It is well known, that the deposition of carbon, from the decomposition of gas at a high temperature, is more abundant in clay than in iron retorts, owing probably to the greater temperature which the former acquire over the latter. Yet, it is to be observed, that, as far as the working is concerned, one retort may apparently be subject to the same conditions as another, but still one of them will be more encrusted with carbon than the other; this may be attributed to the surface of the one which deposits the carbon being rougher than the other.

An experiment was made with twenty D-shaped retorts, set in four beds of five each. They were all worked at the same temperature, charged with the same quantity of Newcastle coal, placed on the same range, and were subject, in every particular, to the same conditions. During these experiments, the resistance offered to the gas, in its passage through the purifiers, and by the weight of the gasometers, or gasholders, was equal to a column of water of 7 inches, by the gauge attached to the ascending-pipe near the mouth-piece. The result was that ten retorts, during the time referred to, had a large accumulation of carbon, amounting in weight to nearly 1 per cent. on the quantity of coal used, whilst the other ten had only a very small accumulation of carbon. These retorts were made by the same manufacturer in the neighbourhood of Newcastle; but ten were made from one seam of clay, and the other ten from clay of a different quality. In the one case, the interior of the retorts in which there was the lesser deposit, was evidently much smoother than the interior of the retorts in which there was the greater deposit. Hence, it is concluded, that the deposition is partly regulated by the nature of the surface, and that it is necessary that the interior of the retorts should be more carefully finished, so as to insure a smooth surface; for which purpose, a proper quality of clay should be selected.

When clay retorts are worked with an exhauster, they are not so liable to the deposition of carbon as when worked without an exhauster; and a smooth surface with an exhauster possesses the same advantages as a smooth surface without an exhauster. As the structure of the mass of carbon deposited in the retorts is always laminated, the principal portion of the carbon appears to separate from the gas at the earlier period of working the charge of coal, and ceases to be separated towards the latter part of the time, so that every time the retorts are charged and worked, there

is a distinct layer of carbon thus formed, which accumulates upon the previous layer.[1]

The quantity of carbon which thus becomes gradually deposited within the retort, at last requires to be removed, as the area of the retort is so considerably diminished, as to prevent the full charge of coal being introduced. The removal of this carbonaceous incrustation, on account of the fragile nature of the clay retorts, requires to be conducted more carefully than in the case of iron retorts. It is necessary, both with clay and with iron retorts, to admit atmospheric air, which has the effect of rendering the carbon capable of being detached, by means of chisel-ended bars. When the retorts are long and have a lid at each end, the air can be at once admitted by removing the lids, but in short retorts having only one lid, the usual plan is to partially remove the lid from the mouth-piece of the retort, and to let it remain in this state until the current of air, which establishes itself through the retort, renders the carbon capable of being easily detached. This process, in some cases, requires to be carried on for from nine to thirty hours, before the removal of the carbon can be effected. The Author has tried various means of accomplishing the object in question, and finds the following to be the easiest, as well as the quickest method. An ordinary lid, provided with a hole, as near the lower part as practicable, and large enough to admit a fire-clay pipe, 3 inches in diameter, is luted on in the ordinary way. The blank flange at the top of the ascending pipe leading to the hydraulic main is then removed, and a temporary connection is made with this pipe to another iron pipe of similar diameter, the other end of which is made to terminate in the main flue of the retort stack leading to the chimney-shaft. The clay pipe being passed through the orifice in the lid, is placed in such a direction, that the end within the retort shall cause the current of air which is drawn through it, to impinge upon the mass of carbon, which it is intended to remove. The inclination of this pipe can be changed from time to time, so that the air may be made to play successively over the whole surface of the carbonaceous mass. A clay pipe is preferred to one of iron, because the latter would be rapidly oxidized. The advantage of this method is, that it requires only half the time for the removal of the carbon. This is of importance, as the longer the retorts are subjected to the action of cold air within, the more they are liable to suffer by becoming cracked, or by the formation of fissures. As the removal of the carbon is one of the practical difficulties connected with the working of clay retorts, it cannot

[1] Specimens to demonstrate this were exhibited.—Ed.

but suggest itself, that the plan which embraces the greatest saving of time, and produces the least injury to the retorts, is to be preferred. Should any more practicable and advantageous method be known than that which has just been described, it is desirable that it should be pointed out.

With respect to the difference in the quantity of fuel required for carbonizing the coal in iron and in clay retorts, the results of practice differ from the statements made by the partizans of clay retorts. It has been found, that where proper judgment and skill are exercised in the construction and working of clay retorts, the quantity of coke required for heating them, in ordinary working, ranges from 25 to 30 per cent. of the quantity of coke made,—assuming that Newcastle coal is used, and that a chaldron of coke is afforded by each ton of coal. Iron retorts may be heated with precisely the same results. In the case of short retorts, the clay retorts possess no economical advantages over those of iron, of the same size, as far as the fuel for carbonization is concerned. But when long clay retorts are employed, say 20 feet in length, then a saving of fuel would be effected, as the same fuel required for heating two beds of iron retorts 7 feet 6 inches long, placed end to end, would heat the clay retorts 20 feet long, thus giving 5 feet of additional length for each retort; that is to say, the brickwork partition required for the iron retorts being no longer necessary, enables the space it occupied to be added to each clay retort, and in this way the quantity of fuel for carbonization is reduced to a per centage varying from 19 to 24. It is to be understood, that the usual time of working both the long and short retorts is six hours for each charge of Newcastle coal.

It appears, then, that the principal advantages arising from the use of clay retorts are:—That there is a saving of about 20 per cent. in the setting, compared with the expense of setting iron retorts; and that the average durability of clay retorts in work is two years and a-half, whilst iron retorts of the best quality only last one year. It may be added, that the first cost of clay retorts does not amount to more than half that of iron retorts, which of itself forms a very important saving in this department of gas engineering.

Mr. HENRY GORE said, he would, in a few words, give the results of his experience in connection with the use of clay retorts. He concurred in the general principles enunciated in the Paper; but he thought the Author had scarcely gone far enough, in meeting the various statements which were continually put forth, with regard to the value of the system, in different parts of the country; the different qualities of coal being taken into account. In discussing the merits of clay retorts, the question of fuel was a matter of serious importance. He would, therefore, mention a few circumstances connected with the description of fuel used, as well as the apparatus employed, in the process of carbonizing. He had had opportunities of obtaining practical information, with regard to the use of clay retorts, in seven, or eight gas-works, situated in different parts of the country, involving the use of almost as many varieties of coal. In Leeds, the coal used for the manufacture of gas was a kind of bastard cannel, found in the neighbourhood of Wakefield and Dewsbury, mixed with about one-third of the ordinary soft coal of the district. With the ordinary iron retorts, the maximum amount of gas obtained was from 7,600 to 8,000 cubic feet per ton. About 37 per cent. of the coke was consumed for fuel. The gas produced had an illuminating power of seventeen sperm candles. Since the introduction of clay retorts, the average make of gas was from 9,100 to 9,200 cubic feet per ton; and he believed that result—considering the specific gravity of the gas delivered to the public—was satisfactory. But the fuel used in producing that quantity of gas, amounted to about 60 per cent. of the coke that was made. London Engineers would, probably, characterize that as a wasteful and negligent process of manufacture; but, it must be borne in mind, that the fuel they had to deal with in Leeds, was totally different in character to that employed in gas-works in London, and in the southern counties generally. The coke itself was light and friable, and contained a large proportion of earthy matter. To keep up a heat in clay retorts, equal to the production of the quantity of gas per ton that he had mentioned, they were obliged to have recourse to, what might be technically termed hard firing, and a much greater draught was essential, than was necessary in London and its neighbourhood. As a striking contrast to the circumstances just related, he might allude to the carbonizing process at Doncaster. The coal used in the gas-works there, was chiefly from the Darley Main, mixed with a portion of the Silkstone seam, from the Thorncliff colleries, belonging to Messrs. Newton and Chambers. This mixture, at a fair working heat, and with six-hour charges, produced about 9,400 cubic feet of gas per ton, of the average specific gravity of 420, and having an illuminating power equal to fourteen and a half candles, whilst they could sell from the yard

nearly 75 per cent. of the coke that was produced. Before, therefore, the economy of clay retorts could be satisfactorily settled, all the conditions affecting the question, both as to the material to be employed, and the form of retort to be used, must be taken into consideration.

Another important point was the mode of setting the retorts. The general plan in London and the neighbourhood was to set them in beds of five or seven, and in some cases beds of eleven retorts, with one, or two fires. No doubt that arrangement was applicable to the nature of the fuel which was obtained in the locality, but in Yorkshire it would entirely fail. At Doncaster, he found, that he could work the retorts, set in beds of five retorts, with one fire, with a satisfactory result, as to the heating power of the furnace; but the wear and tear of the furnace itself was excessive. The same class of bricks that in London would last from 12 to 15 months, at Doncaster would be destroyed in 7 or 8 months. This necessitated an arrangement of setting, that would offer facilities for renewing the furnace, without destroying the retorts. By a mode of setting he had adopted, the entire furnace could be reconstructed, at a cost of about thirteen shillings per set of five retorts. At Lancaster this arrangement was a failure; there the beds of five retorts required two fires, or double the furnace space; but the heat was so much increased, that instead of 9,600 cubic feet of gas per ton, the produce was nearly 11,000 cubic feet per ton. The fuel employed at Lancaster was Wigan cannel, mixed with a small portion of the black coal of Manchester. The average illuminating power of the gas was twenty-one sperm candles.

In order to the determination of this important question, the practice and experience of different localities should be amalgamated; so that instead of having extraordinary statements as to the results obtained at one end of the country, which were not applicable to other places, they might gain a little from each, and thus benefit the general public.

Mr. A. Wright said, the Author of the Paper had pursued an extremely cautious course in dealing with this subject. He had gone over the history of the introduction of clay retorts, and had stated the advantages arising from their use, with a great degree of moderation. It had been stated, that, at Leeds, the ordinary iron retorts produced an average of about 7,600 to 8,000 cubic feet of gas per ton of coal, whilst from the clay retorts an average production of 9,100 to 9,200 cubic feet was obtained. This appeared to be at variance with the results given in the Paper, in which it was said, that the produce was about the same in both cases. Mr. Wright's experience tended to confirm the latter opinion, and he could not, therefore, endorse the statement, that

the use of clay retorts resulted in an increased production of 1,500 or 2,000 cubic feet of gas per ton of fuel. Under particular circumstances that favourable result might be obtained, but he did not think it could be relied on, in general working. The quantity of gas produced from any description of coal depended upon the amount of heat applied. An iron retort being thinner, and having, therefore, less latent heat than a clay retort, cooled down to a greater degree when putting in the charge of coal; and it was some time before it got heated up again to the best state to eliminate gas. Clay retorts being thicker and having a greater amount of latent heat in reserve, were not so much reduced in heat when being charged, and were better fitted to eliminate the gas than iron retorts. At the same time, clay was to a certain extent porous, whilst iron was comparatively impermeable to gas; so that although a large quantity of gas was eliminated in the former case, he did not think any more passed into the gas-holder.

He had given some attention to the question of the leakage of gas from retorts under pressure, and had ascertained, that the leakage was in the direct ratio of the pressure. It was difficult to account for that, the general law of the passage of gas through orifices being, that the leakage was as the square root of the pressure. If an orifice, as, for instance, a gas-burner, was made in a pipe, and a pressure of a column of water of 1 inch was put on, it would deliver a certain quantity of gas; whilst to deliver double that quantity of gas a pressure of 4 inches would be required. He had tried the experiment and found it to be so. That law was generally relied on; but with clay retorts, at a high heat, he had found, that the leakage increased directly in proportion to the pressure. The Author had stated that up to 7 inches pressure clay retorts might be worked economically. In this Mr. Wright agreed; but when they went to 12 inches pressure, the excess of quantity eliminated was more than compensated for, by the permeation through the pores of the retort. In a large number of towns, the gas-works were not sufficiently extensive to admit of the use of the, somewhat costly, process of exhaustion. In such cases he had found, that iron retorts had considerably the advantage over clay retorts, and, he apprehended, it might be taken as a rule, that where a less number than ten retorts were employed, the ordinary iron retort, 7 feet 6 inches long, would be more economical than clay retorts. This would, however, be affected, to some extent, by the price of coal and coke in the district. If coal was cheap, and coke sold at a good price, the latter product would compensate for the leakage in the use of clay retorts.

At the Western Gas Company's works, he had substituted clay

retorts for iron, and, at the present time, he had not one iron retort at work. It was with some hesitation that he had adopted the change of system; because when gas was made at a particularly high heat, bisulphuret of carbon was given off. Now, it was necessary that clay retorts should be worked at a much higher temperature than iron; and so soon as it was attempted to distil coals at a very high temperature, a large amount of this bisulphuret of carbon was produced. It was unfortunate, that, at present, there were no known means of ridding the gas of that impurity. Mr. Lewis Thompson, Mr. Evans, and himself had devoted a great deal of attention, to endeavour to find out some chemical agent for dissipating this impurity, but hitherto without success. No chemical agent had yet been discovered which would remove it, without also, at the same time, removing the entire illuminating matter of the gas. That was the main reason which caused him to delay the introduction of clay retorts, and even now, he did not work them at the high heat which was regarded as the most economical. In the purification of gas, attention was directed to two substances in particular, carbonic acid and sulphuretted hydrogen. These were readily removed by hydrate of lime, oxide of iron, and other processes: and in this Mr. Evans had rendered good service, by the improvements he had introduced. The gas was thus rendered, what was termed, chemically pure from those substances, but the bisulphuret of carbon still remained. The quantity of the bisulphuret of carbon might be represented as varying from 1 to 5, the sulphuretted hydrogen being 40: that was, gas could be made so bad, from the presence of the bisulphuret of carbon alone, as to be equal to from $\frac{1}{40}$th to $\frac{1}{8}$th of the ordinary impurity of gas before purification. Yet by the usual tests it would not be detected, and it was not until it was burnt in a room that it would be discovered.

He agreed with the Author, that the first cost of erection of clay retorts was only about half that of iron; and that the clay retorts would last for $2\frac{1}{2}$ years, whereas iron would not last more than twelve months; but the Author had omitted to state, that when the retorts were made through and through (both ends open) there was less carbon deposited and less fuel used. He considered that the saving in the manufacture of gas, from the use of clay retorts, was threepence per thousand feet. With this, he begged to couple the observation he had already made, with regard to the impurity introduced into the gas, from working at very high temperatures.

Mr. F. J. Evans observed, that clay retorts would not produce the same amount of gas per ton, as iron retorts, if both were at the same heat, when first charged. The best way of testing this, was to draw the charge of coal from each kind of retort, after

it had been at work an hour and a half, and then to look at the state of the 'heat.' It would be found that the clay retort was cooler than the other. The impression with regard to clay retorts was, that as they could be worked at a higher heat than iron, a larger quantity of gas was produced. The bisulphuret of carbon was a nuisance, which, at present, they could not get rid of. Upon this subject, Mr. Lewis Thompson's recommendation was, to leave a small quantity of ammonia in the gas, when the sulphurous acid formed by the combustion of the bisulphuret of carbon combined with the ammonia, ultimately forming sulphate of ammonia, which was innocuous. There could be no doubt that many of the existing Gas Companies had been able to increase their dividends by the use of clay retorts, as the cost of wear and tear was much reduced. He had found clay retorts to last, in good order, for three, or four years, with every prospect of their continuing longer.

In some experiments which he had made to ascertain the leakage of gas through mains, he found that the law of the discharge of gases through tubes, which was, that the leakage was as the square root of the pressure, did not hold good. He had insulated a main, —cutting it off and placing a meter at one end; and had found that the leakage was invariably in the direct ratio of the pressure. If double the pressure was put on, then the amount of leakage was increased two-fold; or, supposing the leakage was 10 cubic feet under the pressure of 1 inch, it would be 20 cubic feet under the pressure of 2 inches. That was an important fact, as regarded the distribution of gas, because it was sometimes thought, that a bad light might be remedied by an increase of pressure, without losing more gas by leakage than was due to the square root of the increased pressure. The leakage here alluded to did not take place through the metal, but was solely due to the joints of the pipes. Some years ago, Mr. Evans had tried the experiment of closing a cast-iron pipe at each end, and allowing a pressure, equal to 4 inches of water, to remain on it for six months. At the end of that time no perceptible amount of gas had passed through, although the apparatus employed was very delicate.

Mr. GORE said, he had made some experiments upon 1,040 yards of iron pipes, 8 inches in diameter, connecting one gas station with another in Leeds. The pressure was increased in the proportion stated, and the leakage obeyed that law exactly. Instead of trying the experiment with a meter, it was made from a gas-holder 10 feet in diameter, accurately graduated, so as to ascertain the result correctly.

Mr. C. MAY inquired, whether the leakage was estimated at 1 inch, or 2 inches of pressure; and remarked, that the difference between the two pressures amounted to only about $\frac{1}{400}$th of the bulk.

Mr. C. W. SIEMENS said, although he would not attempt to point out the *rationale* of the fact, that the leakage increased in the direct proportion of the pressure, yet he thought the experiments of Professor Graham, upon the transpiration of gases, bore somewhat upon this interesting question. Those experiments went to show, that when gases flowed through narrow tubes they did not transpire, or issue, in proportion to the law of gravitation, but according to some totally different law, which had not as yet been clearly laid down. If an explanation might be attempted, he should say, that the gas, in issuing through very small capillary spaces, was so much checked in its progress, that its inertia was destroyed at every step, and it was only the excessive friction which retarded it virtually. But if it was merely the friction that had to be overcome, it would be evident, that the leakage would be in proportion to the pressure applied. This argument would apply in a greater degree with regard to gas than atmospheric air, because the specific gravity of coal-gas was only 0·5 at its ordinary temperature: but when it was heated to 800° in the gas-retort, it would not weigh half as much. The inertia of the gas was, therefore, exceedingly small; but being in a highly-elastic state, the friction was, on the contrary, considerable. Observations had been made on the greater quantity of gas produced from clay retorts than from iron retorts. Although he had had no practical experience in this matter, he would suggest, whether in those cases where the greater quantity of gas was obtained, the exhauster had not been worked to a great extent; so that the leakage through the walls of the retort was from the exterior to the interior, or into the retort.

Mr. W. STRODE said, that a fact, however simple in itself, might be important in the discussion of this subject. At a small gas work, at Chipping Norton, he had used coals from the Staveley Works, near Chesterfield. With iron retorts he produced, on an average, 9,000 cubic feet per ton. About two, or three years ago, he adopted small clay retorts, of the D shape, made of Stourbridge clay; but he did not find any increased production of gas worth mentioning, in fact it was about the same both in quantity and quality. Generally speaking, he did not think clay retorts were applicable to small works; but where the heat could be constantly kept up, and an exhauster applied, no doubt they could be used with advantage. In one point of view they even had advantages in small works; that was, where tar was a drug, for it could be applied to the fire, and an excessive heat be obtained by it without injury to the clay, although it would be very detrimental to an iron retort. He had therefore adopted the plan at Chipping Norton, of using clay retorts, burning the tar, in the winter, and iron retorts, burning coke, in the summer. At Banbury, Mr. T.

A. Hedley, Assoc. Inst. C.E. used long clay retorts, with lids on each end, put together in two, or three rings, and set in beds of four, or five over one fire. There, from the Staveley coal, only a little more than 7,000 cubic feet of gas per ton was obtained, on an average, or nearly 2,000 cubic feet per ton less than Mr. Strode obtained, from the same coal, with the small D-shape retorts, made of Stourbridge clay.

Mr. E. GODDARD said, his experience in the use of clay retorts, accorded with that of the Author. He had had some in operation for three years, and they appeared now to be in as good condition as they were a year ago. He had not found the produce of gas from the clay retorts so much greater than from iron retorts, as had been stated. The formation of carbon took place more rapidly, when the retorts were rough upon the inside than when they were smooth. He had, sometimes, entirely cleared the retorts of the carbonaceous deposit, by the introduction of a fine jet of water.

Mr. FRASER remarked, that in Scotland, fire-clay retorts had been used for thirty years, and for nearly twenty years exclusively, in every work, of any size, except one. In every case (with this exception) where one, or at most, two clay retorts could be continuously worked, the Scotch managers never thought of using iron retorts. He had visited nearly all the gas-works in Scotland, and had supplied clay retorts regularly to upwards of one hundred works, and he could confirm the statements made in the Paper. There was no doubt, that smoothness of the internal surface of retorts reduced the amount of carbonaceous formation. As a natural consequence, retorts with smooth internal surfaces were most in demand. This was first brought to his notice by the manager of the Montrose gas-works, who subsequently wrote him, that Inverkeithing retorts were not so liable to the carbonaceous deposit, as other retorts that had been tried. A simple plan of removing the deposit of carbon was followed at Stirling, and some Scotch works. This was to throw a little common salt into the retort, which, it was stated, with the admission of atmospheric air, dissipated the carbon very quickly and effectually. The amount of coke required as fuel for carbonizing, depended on the quality of the coal. In Scotland, where they principally used fine cannel coal, scarcely an ounce of coke was left to heat the retorts. Torbane-hill and Kirkness best cannel coal left none whatever; all the carbon being carried off with the hydrogen. It was thought very good working, if sufficient 'char' was left, even with second-class cannel coal, to keep the retorts going. He could, from his own personal experience, confirm the statement made with regard to the increased dividends paid by Gas Companies, consequent upon the saving effected by the use of clay

retorts. He knew several instances of Companies, in small towns, which formerly paid only 1 or 2 per cent., now paying 4 and 5 per cent.; and he had heard managers of small works say, that they could not give a dividend until they adopted clay retorts. With regard to the economy in the first cost of, and in setting clay retorts, he had returns, furnished by the Dunfermline Gas Company, showing that the cost of iron retorts, including protections and setting, was £154 per annum, as compared with £20 for clay retorts. Other returns showed a difference as between £120 to £160 per annum for iron, and £23 for clay retorts. He calculated the cost of clay retorts as only one-eighth that of iron, including the setting; and their durability was much greater.

Mr. C. MAY suggested, with regard to the interior surface of the retorts, whether the salt did not act simply by glazing the surface. The pottery wares at the Vauxhall-works were glazed by salt. It was said, that the smoother the retort was on the inside, the less would be the deposit of carbon; and it was reasonable to suppose, that the salt glazed the retort, and thereby prevented the deposit.

Mr. FRASER remarked, that the salt was employed, in the instance he had mentioned, solely to dissipate the carbon after it was formed, and not to give a glaze to the retort.

Dr. MAUGHAM said, it was generally considered, that the carbon was derived from the coal gas undergoing decomposition; the volume of gas becoming expanded by the heat of the walls of the retort, whilst a portion of its carbon was deposited upon the retort. He thought, on the contrary, that the derivation of the carbon was from a portion of the tar. The vapour of tar generated from the coal consisted of a number of compounds, that was to say, it was not homogeneous, but heterogeneous. The coal did not contain a single compound ingredient that it produced;—neither gas, nor tar, nor any of the other compounds derived from it; but when undergoing destructive distillation, part of its several elements reunited and formed various volatile compounds, which passed off with the gas. A portion of the carbon, however, contained in the tar, having nothing to combine with, became deposited in the retort. If a constant current of air could be kept through the retort, which was impossible, the carbon would not remain; but in the absence of oxygen, or some other element, which would carry it away, it was deposited.

Mr. JOSIAH F. FAIRBANK remarked, through the SECRETARY, that he did not think the merits of iron retorts had been fairly stated. He had had some iron retorts in constant work for two and a-half years, and the quantity of gas produced by them was quite equal to what had been stated as having been eliminated

from clay retorts. He would, at some future time, prepare a Paper on the subject, for reading at the Institution.

Mr. T. HAWKSLEY stated, that the course the discussion had taken might lead to erroneous conclusions; for, although there could be no question, that clay retorts, when well set and carefully managed, might endure twice, or thrice as long as iron retorts, and that the materials of these retorts, and also of their settings, were cheaper than those of iron retorts, yet on the other side of the account must be placed several important items of charge, which, under certain circumstances, would turn the balance in favour of iron retorts, and under certain other circumstances would render it a matter of indifference which description of retort was used; but there were circumstances under which clay retorts might be preferred. Now, let the following practical case be assumed: let the cost of an iron retort, mounted for use, be £10, and of a clay retort, also mounted for use, be £7. Let the durability of the latter be two and a-half times that of the former, and let the quantities of gas made in each be respectively 900,000 cubic feet and 2,250,000 cubic feet prior to final destruction. Granted, also, that the sale price of coke was 15*s.* per ton, the consumption by iron retorts three-tenths of the quantity made, and by clay retorts four-tenths of the quantity made, and let it be admitted, that one ton of coal carbonized would produce two-thirds of a ton of coke—then the amount for equal productions of gas would stand thus:

	Iron Retorts.			Clay Retorts.		
	£	s.	d.	£	s.	d.
1. Materials and Setting	£10 × 2½ = 25	0	0	7	0	0
2. Extra Repairs of Furnaces, &c. .				1	10	0
3. Expenses of Exhauster, &c. . .				1	5	0
4. Blowing-out Apparatus, &c. . .					5	0
5. Coke used in Furnace	37	10	0	50	0	0
Total	£62	10	0	60	0	0

This showed that when coke would sell at 15*s.* per ton, and the other circumstances were as stated, iron retorts and clay retorts were of nearly equal value. If coke was dearer, iron retorts were to be preferred; and if it was cheaper, clay retorts should be preferred. Coal, however, varied much in quality, and so did the quantity and quality of the coke produced, and hence the gas-engineer must, in every case, be governed by the particular circumstances with which he had to deal.

Clay retorts were well adapted for generating gas from the Scotch cannel coal, which produced coke of no appreciable value; but it might be doubted, whether they were, in useful effect, equal

to iron retorts, for the distillation of coals containing, or yielding, a large quantity of liquid matter, as, for instance, with coals which yielded 350 lbs. per ton of ammoniacal liquor, instead of the usual quantity of 100 lbs. Nor, were they to be commended for small works, using coal producing valuable coke, for in such works an exhauster could not be applied; neither was the management and employment of the retorts so careful as in larger establishments, conducted under intelligent and experienced supervision. An error had been committed, in supposing that clay retorts could be worked at a pressure of 7 inches of water, with more advantage than at low pressures. Clay being a porous material, allowed the gas to transpire through its capillary passages, and hence it was better to work under a low pressure. Neither was it correct to say, that clay retorts would produce more gas than iron retorts, or gas of better quality. In fact, clay retorts would not evolve more, nor indeed so much, gas as iron retorts, if they were not, by the expenditure of a much larger quantity of fuel, sometimes worked at a much higher temperature than would be prudent with iron retorts. In many such cases, however, the additional quantity was obtained, not only at the expense of the illuminating power, but also at the expense of purity.

Much had been said, with respect to the supposed anomaly of the law of leakage through the substance of clay retorts—the quantity being found by experiment to be as the pressure, rather than as the square root of the pressure. This, however, was no real anomaly, for the law of the transmission of fluids through tubes was well known to be represented by the formula

$$P \propto av^2 + bv$$

in which P represented the pressure, v the velocity, and a and b two experimental coefficients. Now when the motion was minutely slow, as it always was through capillary tubes and porous substances, v^2 became indefinitely small in respect of v, and consequently

$$v \propto P$$

or, in other words, the quantity lost was as the pressure placed upon the retort. The same law obtained in the leakage of gas from mains; and hence, by mere observation, it was discoverable whether the loss was from a broken pipe, or from capillary apertures; because, in the former case, the loss under a given head P would be as $\sqrt{P}$, while in the latter case it would be as P simply.

In respect to the greater deposition of carbon in clay retorts, he believed that this arose, in a considerable degree, from the decomposition of the gas transpiring through the substance of the

retort. The gas parted with its carbon while entering the highly-heated pores, and the carbon was, consequently, left on the inner surface of the retort.

Mr. CHURCH observed, in reference to the statement, that an increase of 1,600 cubic feet of gas per ton of coal, was made by the introduction of clay retorts, as compared with the quantity obtained by iron retorts, that, in this case, either the iron retorts were not heated to the proper temperature, or the gas made from the clay retorts was of an inferior specific gravity, and, consequently, of low illuminating power. Experiments of this kind were of little value, unless the comparative illuminating power of the gas obtained was also given, as the quantity alone must lead to fallacious conclusions. With reference to the remarks as to the evolution of the bisulphuret of carbon, it should be observed, that the quantities generated were, as nearly as possible, the same both in clay and in iron retorts, when worked at equal temperatures. There was good evidence to prove, that when gas was made at very high temperatures, a much larger quantity of the bisulphuret of carbon was evolved; hence the necessity of working clay retorts at about the same temperature as those made of iron. By leaving in the gas a small quantity of ammonia, the effect of the bisulphuret was neutralized. When clay retorts were worked under proper conditions, they produced gas of equal illuminating power and purity, as iron retorts. The calculation which had been made, with a view of showing, that the merits of iron retorts had not been fairly set forth in the Paper, differed widely from the results of his practice. The fact of clay retorts having become almost universally used by Gas Companies was, in itself, a strong argument in support of the conclusions given in the Paper. The cost of this department of gas manufacture had received the greatest attention from engineers, who had been compelled to exercise the most rigid economy, in wear and tear, to meet the public demand for cheap gas. It was to be regretted, that the standard of purity, and the value of the illuminating power of gas, were not rightly estimated by the public, who only appeared to consider the price per 1000 feet at which it was supplied. Every Gas Company which had fairly tried clay retorts, was convinced, by the balance-sheet, that a considerable saving was effected by their use, as compared with iron retorts; and that clay was a more suitable material for the distillation of coal than iron. Some misconception appeared to have arisen as to the best pressure at which to work clay retorts. He had stated, that there was a great advantage in working with an exhauster, at a minimum of pressure, and that without an exhauster, the maximum of pressure should be 7 inches of water. When the pressure was increased, the leakage was in the same ratio; hence the necessity of working

at as low a pressure as possible. The reason why he had given 7 inches, was from the fact, that with the ordinary apparatus, without an exhauster, the resistance was equal to the pressure, and could not practically be reduced below it. Short clay retorts did not require a larger quantity of fuel for heating them than iron retorts, assuming coke made from Newcastle coal to be used. When long clay retorts were used, a saving of at least five per cent. of fuel was effected, as compared with iron retorts.

Mr. G. H. RAMSAY remarked, through the SECRETARY, that he had made clay retorts thirty-five years ago, and had some of them by him now. They were circular, 15 inches in diameter, and were made of fire-clay. Had they been used with an exhauster, he did not doubt that they would have proved quite equal to any now manufactured. Great skill was necessary for making retorts; both the composition of the material, and the mode of manufacturing, requiring to be carefully attended to. The setting, and treatment after being set, devolved upon the engineer. When well set they would last three, or four years, but he did not think it economical to work them too long. At the City Gas Works some of his retorts had entered upon their third year, and some had lasted even longer. An exhauster still appeared to be necessary for working clay retorts; and this might be expected to be the case, as long as the Gas Companies bought low-priced retorts, of indifferent quality, as many of them did. If, however, greater encouragement was given to the manufacturers of good retorts, the Companies would soon perceive the advantage, and in time the expense of exhausters might be avoided.

March 10, 1857.

ROBERT STEPHENSON, M.P., President,
in the Chair.

No. 961.—"On High Speed Steam Navigation; and on the Relative Efficiency of the Screw Propeller and Paddle Wheels."[1] By ROBERT ARMSTRONG.

THIS Paper having been published by the Author, "without the previous consent of the Council," contrary to the regulations of the Institution, (Section XIV. of the Bye-Laws,) cannot be published in the Minutes of Proceedings. As, however, it led to an interesting discussion, it has been determined so far to depart from this rule, as to print the Abstract of the Paper, which was issued at the time.

ABSTRACT.

The first part of the Paper was devoted to the consideration of the circumstances which appeared to limit the maintenance of higher speeds, than were now attained by steam ships, in deep sea navigation, and the causes which had hitherto prevented the asserted high speeds of steam navigation, on the American rivers, from being attained in England.

It was remarked, that it was of primary importance, in calculating the velocity of steam ships, to "separate the performances of the machinery from the question of the form of the vessel," for it was believed, that the increased effective power of the engines had been completely neutralized by the theory of the sharp water-line, and that the speed which had been hitherto attained, was not due so entirely to the skill of the naval architects as had been asserted. Where great speed had been obtained, it was shown, that it was always with a proportionately small midship section, augmented length, and increased steam power, above the ordinary proportions of other steam ships.

It was argued, that the propelling power was as the square of the velocity, and not as the cube, which was the prevailing opinion, and that the formula based on this law, and on the fact that one

[1] The discussion upon this Paper extended over a portion of four evenings, but an abstract of the whole is given consecutively.

effective H.P. was required for one square foot of midship section, to produce a velocity of 10 miles per hour, would be,—

$$V^2 \text{ (in miles)} = \frac{\frac{2}{3} \text{ I.H.P.} \times 100^1}{\text{Mid. Section.}}$$

It was shown, that the actual speed of sixteen out of twenty-nine screw steamers was within 10 per cent. of the speed calculated by this formula, the results being given in a table, in which the midship section, the indicated horse-power, the actual speed in miles, the pitch of the screw, and the number of revolutions per minute, were given. Variations from the formula might arise from imperfections of the engine, the form of the propeller, and the immersion of the vessel. The midship section was not always the greatest section to the line of motion, especially in screw steamers, and at velocities of 13 miles per hour, or upwards, the immersion of the after end rapidly increased. With coarse pitched screws, the actual speed was less than that calculated by the formula. It was suggested, that the "angle from the axis of the screw" would be a better expression for the pitch than that now adopted.

The Report of the trial of the French war steamer 'Charlemagne' was quoted in support of the Author's views. With two boilers there was an expenditure of 3,064 lbs. of coal, to propel the vessel at the rate of 8 miles per hour, and with three boilers the consumption was 2,659 lbs. of coal, to attain the same speed; whilst with four boilers, and a consumption of 5,733 lbs. of coal, the speed was 10·9 miles per hour. According to the square theory, to attain a speed of 10·9 miles per hour, with two and three boilers respectively, would involve an expenditure of fuel as shown in the following proportions:—

$$8^2 : \underset{\text{lbs.}}{3{,}064} :: 10{\cdot}9^2 : \underset{\text{lbs.}}{5{,}688}$$
$$\text{and } 8^2 : 2{,}659 :: 10{\cdot}9^2 : 4{,}936$$

whilst according to the cube theory these proportions would be

$$8^3 : \underset{\text{lbs.}}{3{,}064} :: 10{\cdot}9^3 : \underset{\text{lbs.}}{7{,}749}$$
$$\text{and } 8^3 : 2{,}659 :: 10{\cdot}9^3 : 6{,}744$$

whereas the actual consumption with four boilers for a speed of 10·9 miles per hour was, as before stated, 5,733 lbs., the midship section being in both cases nearly equal. This Report also showed a saving of fuel of 4 tons per day, by increased boiler space. It was stated, that in sea-going steam ships, 5 lbs. of coal per diem might be taken as the consumption of one effective H.P. It was

[1] This formula is strictly empirical, and is based upon the amount of power required in the 'Himalaya.'—AUTHOR.

remarked, that the system adopted in the French Navy, of recording, in minute detail, the results of the trials of their steamers, was to be commended, and that it was one well worthy to be extended to this country, as it could not fail to be of essential service in the improvement of naval architecture.

From the arguments adduced, the Author concluded:—

1st.—That in the separation of the performances of the machinery from the question of the form, in calculations of velocity, the duty of the naval architect was merely to provide the requisite displacement at which the vessel would float, with the proposed immersed midship section, and to give the stability, the strength, and other properties required in a vessel, all considerations for velocity being entirely the province of the engineer.

2nd.—That the rate of sailing between two vessels, with an equal moving power in each, did not depend on the form of water-line, but entirely on the area of the greatest section to the line of motion.

3rd.—That displacement in the line of direction did not materially add to the resistance; and

4th.—That the friction between the sides of the vessel and the water need not enter into any calculation, for any required velocity.

It was asserted, that the requisite principles were not fulfilled, for the maintenance of higher speeds, than were now attained by steam ships in deep sea navigation, and that the length of the vessel was the most important element for this purpose. A comparison was drawn between H.M.'s Yacht 'Fairy' and the 'Himalaya,' the speeds of which were nearly identical, whilst the other proportions were very dissimilar, as the latter was thrice the length, had twenty times the displacement, and yet had only five and a half times the power of the former. It was believed, that an increase of 200 feet in the length of the 'Himalaya' would be advantageous, as it would enable 2,000 tons of extra cargo to be conveyed at the same velocity; and by doubling the present power on board, a speed of 22 miles per hour might be obtained, with an increase in the consumption of coals of only 300 tons, still leaving space for 1,000 tons of cargo, with the same immersed midship section. If a further extension of length of 200 feet was made, the displacement would be increased three times, and the power being similarly increased, a speed of 27 miles per hour might be obtained, and the distance from Liverpool to New York be accomplished in five days. The proportions last indicated were, it was thought, very similar to those of the 'New World,' one of the most recent of the American river steamers. It was shown, from Admiralty records, that the four vessels having the largest proportional displacement to nominal horse-power, and also to the midship section,

were the most efficient for speed; proving that the midship section, and not the weight, was the sole basis for calculations of velocity, and that displacement in the line of direction did not increase the resistance. It was believed, that the 'Great Eastern' steam ship, now building, would be propelled at the rate of 18 miles per hour, if the engines worked up to the same indicated horse-power as the 'Himalaya' and that 10 tons would be conveyed at the same speed and cost as $4\frac{1}{2}$ tons.

When the fact was received, that the midship section was the sole basis for calculations of velocity, the best form of water-line could soon be decided, and the stability, and other requisite conditions, in the construction of vessels, could be established. Then with a form of vessel increased in length amidships, without the risk of that continual change which had existed during the last twenty-five years, and which was a strong proof of the absence of established principles in Naval Architecture, machinery could be most profitably employed in the building of ships.

In the second part of the Paper the relative efficiency of the Screw Propeller and Paddle Wheels, when applied to vessels of identical form, tonnage, and steam power, independent of the use of sails, was considered. For this purpose the trials of the 'Himalaya,' a screw steamer, with the 'Atrato,' a paddle-wheel steamer, were referred to. The engines were valued by their efficiency, £50 per nominal horse-power being taken as a basis for testing their economy, the consumption of coal per effective horse-power, and that required to propel one ton of displacement a given distance were calculated, and the efficiency of the vessels for velocity was tested by a common standard of resistance. From this it resulted, that—

	Himalaya.	Atrato.
Value of Engine per Effective H.P.	£25 12 0	£32 1 0
Consumption of Coal per Effective H.P.. . . .	5·5 lbs.	6·3 lbs.
One ton of displacement carried one mile by . .	·146 lb.	·181 lb.
Ratio of Actual Rate to Rate given by Formula .	100	83

The engines of the 'Himalaya' were therefore 20 per cent. more efficient than those of the 'Atrato,' the consumption of coal was 14 per cent. less, the displacement bore about the same per centage, and the efficiency for speed, in these two examples, was that the paddle wheel was 17 per cent. less than the screw propeller.

Mr. ARMSTRONG suggested, that the discussion should first be taken upon the question, whether the propelling power varied as the square, or as the cube of the velocity. The latter theory was the one generally received as correct, and if it was proved to obtain, all the deductions he had drawn from the opposite theory would of course be erroneous. What he intended to convey was, that in all cases the resistance was as the square of the velocity, and that the propelling power was in the same proportion as the resistance. The speeds were given throughout in statute miles.

Mr. J. SCOTT RUSSELL said, the Admiralty experiments were recorded in knots. He had some difficulty in arriving at the exact ideas of the Author on several points. In some instances the phrase employed was "that the resistance was as the square of the velocity;" in others, "that the indicated horse-power was as the square of the velocity." There seemed to be some confusion in the Paper, in the use of the terms "power," "force," and "resistance." Power was the force developed in a given time, and consisted of two elements,—force, and the space moved over. All naval constructors agreed, that the resistance and the moving forces varied as the square of the velocity; and in calculating the resistance, or force necessary to propel the vessel, they had always taken the area of the largest, or main section, as the principal element. Now, if the resistance was as the square of the velocity, then the horse-power expended, multiplied into any number of square feet of main section, must, as a mere mathematical rule, be as the cube. For instance, if the resistance to 1 square foot of midship section, propelled at the rate of 5 miles an hour, was 5 lbs., then, according to the usual known law of the resistance being as the square of the velocity, the resistance at 10 miles an hour would be four times five, or 20 lbs. But this latter resistance acted over double the space, so that the result must be again doubled, for the measure of the power expended; and hence, the power developed in one hour, was necessarily and unavoidably as the cube of the velocity. The Author's proposition about the measure of power was, therefore, in direct contradiction to his admission as to resistance. Mr. Russell held, that no further discussion was necessary upon that subject; but all that had been advanced about resistance, in so far as correct, must be allowed, as being merely what everybody already knew. The Author was, however, entitled to demand, that his theory should be tested, not merely by the ordinary rules of arithmetic, but also by facts and figures. The figures which had been brought forward in the Paper, must be assumed to be, and be taken as, facts soundly calculated; but unfortunately for the Author, they overthrew his arguments. One table contained collected facts, and another selected facts; the latter approaching the nearest to the demonstration of the "square" theory. In this selection, the

"square" theory was nearer to the fact than the "cube" theory, or ordinary rule, in the cases of the 'Minx,' 'Himalaya,' and 'Vulcan;' whilst the ordinary rule was much more nearly correct in the 'Archer,' 'Dauntless,' 'Fairy,' and 'Plumper.' The selected facts, therefore, failed to prove the rule they were intended to support. In the table of collected facts, the actual speeds were

8·4, 9·4, 8·9, 9·4, ... 8·7, 10, 12, 7·2

The speeds calculated by the "square" theory were

7·0, 7·7, 7·8, 8·4, ... 10·15, 13, 14·7, 11·83

Thus, it would be seen, that there were two diverging series of figures, which, arranged in columns, side by side, must agree somewhere about the middle. At the commencement of the table, the formula gave the speed as less than it really was; in the middle, fact and calculation nearly agreed; whilst at the end of the table, the rule gave results greatly in excess of the truth. If that was to prove the formula, he confessed he had yet something to learn in the mode of proving a formula. The time had not yet arrived when a simple formula would make a ship go fast, nor when the shape and lines of a ship could be disregarded, nor could it be admitted that, by merely allotting so many horses' power per foot of midship section, so much more speed could be obtained.

He recollected witnessing an experiment, the first of the kind he had seen, at the measured mile on the River Thames, whilst the late Mr. Ewart was Inspector of Machinery for the Admiralty. Two engines of 50 H.P. were taken out of a man-of-war, and were replaced by a pair of engines of 60 H.P. The practical result of the alteration was, that only one-twentieth part of a mile more speed was obtained by the engines of 60 H.P., than by those of 50 H.P. That was one of the first facts to satisfy his mind, that horse-power was not everything, but that the shape of the ship was something; and he determined, if possible, in future not to trust to mere horse-power, but to see what could be done by the shape of the ship. Soon after that, he had an opportunity of superintending the building of four timber ships of the same dimensions, the same displacement, and the same horse-power; but each had different lines, being constructed by four different builders. The engines were all alike, being made by the firm to which he belonged, and the same firm also built one of the vessels. The result was, that upon a run of 16 miles, their several speeds were 12½—12—under 11—and something between 10 and 11 miles per hour. He would mention another instance; a steam-vessel, constructed to go both ways, but built with one fine end, and the other less fine, as an experiment, went fully a knot faster one way than the other, although the midship section and the horse-power were necessarily identical at all times. This showed,

that there was something more than engineering in the construction of a steam-vessel. He afterwards built four other vessels, of identical length and breadth, the other conditions being similar; the result was, that in one ship the resistance was double what it was in another. That being the case, he thought there was no reason to doubt the correctness of the general rule, that the resistance of similar forms was as the square of the velocity, and the horse-power as the cube of the velocity, which came very near to the results of practice; where the forms varied no such conclusion could be warranted. If it was said, that Naval Architecture had not made as much progress in the present century as might have been expected, it was not, at least, owing to a want of formulæ.

Mr. Russell thought it very desirable, that they should have good facts and experiments, and not new formulæ, and that results should be attributed to their proper causes. Experiments were still wanting, to determine how much force it took to drag a vessel of a given shape and a given size through the water, at a given speed. The experiments should be made by towing vessels, so as to get true measures of resistance, without being mixed up with the engine and the slip of the paddle-wheel. He suggested, that the Government should institute a series of experiments for this purpose, and that the 'Duke of Wellington' should be towed by several steamers with a rope, at speeds of $2\frac{1}{2}$, 5, $7\frac{1}{2}$, and 10 knots per hour, and the drag upon the rope be ascertained by means of a dynamometer. A similar series of experiments with such a vessel as Her Majesty's yacht, which had fine lines and great length, would give results from two totally different classes of ships; and such experiments would do much more to advance the science of Naval Architecture, than the mere construction of empirical formulæ.

Mr. DINNEN remarked, through the SECRETARY, that a series of trials made by him in 1852, in the channel, and under the same circumstances, on board H.M.S. 'Desperate,' of 1,037 tons burthen, and 400 nominal horse-power, confirmed, in a remarkable degree, the usually received theory, that the velocity of the ship varied as the cube root of the power, and not as the square root. The trials were usually of eight hours' duration; but were occasionally brought to a close in six hours, or less, if circumstances threatened to affect valuable results already obtained. The steam was kept at a constant pressure in the boilers, and indicator diagrams were taken from each of four cylinders every quarter of an hour; the mean of the whole being taken for the exponent of the trial. The revolutions of the engines were taken by two counters, and the speed of the ship by three patent logs—the mean, of course, being taken for the results. The engines were adapted for being

readily separated into pairs. The results of these trials, expressed in a tabular form, were thus recorded :—

Experiment.	No. of Trials.	Depth of Water.	Indicated H.P.	Speed in Knots.	Mean Expenditure of Coal per Indicated H.P.
		ft. in.			lbs.
No. 1, with 4 boilers and 4 cylinders	3	15 6½	805·894	9·147	4·61
No. 2, with 3 boilers and 4 cylinders expansively . .	2	15 8¾	579·319	8·248	5·13
No. 3, with 2 boilers and 4 cylinders expansively . .	2	15 6¾	363·867	7·352	5·58
No. 4, with 1 boiler and 2 cylinders expansively . .	1	15 1	169·32	5·981	5·89

Now, if, as had been for a long time received, the velocity of the ship varied as the cube root of the power, and not as the square root, it would be expected, that the index of the full power, as well as of the others, would correspond. This they did in a most remarkable degree. The slight difference in the draft of water of the ship could not materially affect the results, inasmuch as he had known three times the difference to be immaterial to speed and power, when the lines did not alter rapidly. Many other illustrations might be adduced, as to the law of the relation of power to velocity, confirming the results of the trials with the 'Desperate.'

In these trials, the expenditure of hand-picked Welsh coal, per indicated H.P. per hour, was never lower than 4·4 lbs., nor higher than 5·9 lbs. in any of the experiments, the least economic result being obtained when only one boiler, out of four, was employed. The consumption of 4·4 lbs. might be taken as the most economic expenditure per indicated H.P. per hour of the engines in question, at their fullest work, with clean Welsh coal, urged to a rate of combustion of about 18 lbs. per square foot of grate per hour, with four boilers.

Mr. C. ATHERTON observed, through the SECRETARY, that he believed the Author of the Paper under discussion attempted to establish the following propositions :—

1st. That the comparative speed of two vessels, with an equal moving power in each, did not depend on any form, but entirely on the area of the immersed midship section, or the greatest section at right angles to the line of motion.

2nd. That with a given sectional area, additional displacement in the line of motion did not materially add to the resistance.

3rd. That to propel a vessel twice as fast only four times the power was required.

4th. That the amount of friction between the hull and the water did not affect the calculation for any required velocity.

In these propositions Mr. Atherton could not concur, for the reasons which he would briefly state.

With regard to the first proposition, H.M.S. 'Rifleman,' originally with 348 indicated H.P., only attained a speed of 8·09 knots per hour, but when her stern lines were altered a speed of 9½ knots was attained, with 367 indicated H.P., and when the power was reduced to 188 indicated H.P., the speed was 8·01 knots; being nearly identical with the speed which originally required 348 indicated H.P. Again, H.M.S. 'Teazer' originally required 176 indicated H.P. to attain the speed of 6·31 knots; but with reduced engines, working to 128 indicated H.P., after the stern lines had been made finer, the increased speed of 7·68 knots was attained. H.M.S. 'Bann' and 'Brune,' fitted with a rudder at each end, and, therefore, capable of being worked at full power in either direction, were found to have a greater speed when going ahead, than when going astern, the indicated horse-power being the same in both cases. Experimental trials with H.M.S. 'Dwarf' showed, that the speed could be reduced to less than one half, by filling up, or doubling upon her stern lines; and the original speed could be again restored by removing the doubling—the indicated horse-power being in both cases the same. In all these experiments, the midship section of the respective vessels was in no way interfered with, and the hulls were clean at the time of trial.

With reference to the second proposition, estimating the comparative dynamic duty of vessels by the generally received law—$\frac{V^3 D^{\frac{2}{3}}}{\text{Ind. H.P.}}$, his experience led him to believe, that there was a limit to the advantageous increase of the length in proportion to the beam. The decrease of resistance, resulting from the finer lines, obtained by an extension of length, was, after certain limits, more than neutralized, by the increase of frictional resistance, occasioned by the corresponding increase of surface.

With regard to the third proposition, on the relations of power and speed, H.M.S. 'Minx,' when propelled by 31·6 indicated H.P., attained the speed of 4·51 knots per hour, but to propel the vessel at 9·14 knots required 234 indicated H.P., or nearly as the cube of the speed. By the "square" theory, the speed (9·14 knots) ought to have been attained by 130 indicated H.P. The same rule, that the power varied, *cæteris paribus*, as the cube of the speed very nearly, had been found to obtain with H.M.S. 'Banshee,' which had been adapted for different services, requiring a variation of speed from 12 knots to 16 knots.

In reference to the fourth proposition, it was quite common, in Her Majesty's service, for vessels to be tried at the measured knot, before leaving the Thames for foreign service, and again after their return. It was thus frequently found, that the speed was reduced as much as 20 per cent., the indicated horse-power being the same in both cases, attributable solely to the foulness of the bottom. Under these circumstances, it would require double the power to attain the original speed.

As regarded the relative efficiency of the screw-propeller and the paddle-wheel, he believed, that either one, or the other, might be practically misapplied, to the extent of neutralising 30 per cent. of the engine power; and that erroneous conclusions were frequently arrived at, in consequence of such misapplication of the principles, or instruments, intended to be compared with each other. The extent to which conclusions, based on steam-shipping experiments, were liable to be delusive, might be judged of from the fact, that very few publicly promulgated reports of steam-ship trials contained even the elements of investigation, on which any sound judgment whatever could be formed, as to the merits of the practical result. And since the relative merits of different propelling instruments and means, such as the paddle-wheel, the screw-propeller, and the water-jet, of different kinds, and of different applications of the same principle, must, popularly, be a practical, rather than a theoretical inquiry, it followed that little could be done in this inquiry, unless the law was agreed upon, by which the dynamic results of the respective appliances might be judged of and compared. Subject, therefore, to the generally recognised law before referred to, he was enabled to state, that the highest index numbers of dynamic duty that had come to his knowledge, or had been credibly reported to him, had been the productions of the screw propeller; and this was confirmed by the fact, that on comparison of the indicated and effective powers of paddle-wheel and screw-propeller vessels, attached to a fixed dynamometer, the highest ratio of effective to indicated power, known to Mr. Atherton, had been obtained by the agency of the screw propeller.

The subject of high speed steam navigation, especially with respect to the mutual relations of speed and cost, had been fully inquired into in the second edition of his "Essay on Steam Ship Capability."[1] He therein showed, that the cost per ton weight of cargo, of performing long voyages, at high rates of speed, with steam-ships of ordinary magnitude, increased in such a rapid ratio as would scarcely be credited in discussion; but it was a subject illustrating the capabilities of large ships pre-eminently worthy of

[1] *Vide* "Steam Ship Capability." By C. Atherton. 8vo. London, 1845.

private study, on the part of all who were interested in steam-shipping affairs.

Mr. PHIPPS said, that the arguments adduced in the Paper under discussion were utterly at variance with all recognised principles. One point, in particular, he would advert to. The Author ignored, altogether, the effect of the friction of their immersed surfaces upon the speed of vessels. Mr. Phipps had calculated, as nearly as he could, from the data accessible to him, the number of superficial feet presented by the immersed portion of the hull of the 'Rattler,' a vessel of which all the particulars were perhaps more generally known than of most others. That vessel had an immersed surface of about 7,000 square feet, and according to the experiments of Beaufoy,[1] on the friction of immersed surfaces, at 10 knots per hour the friction was eight-tenths of a pound on every square foot, and at a speed of 11 knots per hour, the friction was very nearly 1 lb. per square foot. At the former speed and friction, the power absorbed might be taken as equivalent to 170 H.P. What could be thought, therefore, of a theory which, in the case of the above vessel, would entirely disregard a loss equal to 170 H.P., when the total indicated power of the engines amounted only to 428 H.P.? It was a well-understood principle in ship-building that, within given limits, when the length was increased power was economised; but to assert that this could be done without any limit, was, for the reasons above given, evidently absurd.

The importance of discovering the true resistance of vessels, moving through the water at different speeds, relative to which there were not at present any reliable data, could not be over-rated. The experiments which had been made on this subject with the 'Rattler,' were inconclusive, inasmuch as the dynamometer applied to the end of the driving shaft of a screw vessel must show different and higher results than would be the case if the dynamometer was applied to the shaft of a paddle-wheel vessel of similar dimensions. His reason for thinking so was, that as the action of the screw neutralised, to a great extent, the current coming aft, and momentarily filling up the cavity left by the vessel's stern, the minus resistance would be thereby increased, and the pressure on the end of the screw shaft would be greater than the tension to which a cable would be subject, when applied to tow a similar vessel.

Mr. WIMSHURST said, ever since he built the 'Archimedes,' the first screw-steamer, he had been impressed with the paramount importance of giving fine lines to all auxiliary steam-vessels; in fact, that they should be as efficient under sails alone as under

[1] *Vide* "Nautical and Hydraulic Experiments, with numerous Scientific Miscellanies." By Col. M. Beaufoy. 3 vols., 4to. London, 1834.

steam. If so much power was required to obtain an increased speed, it was evidently important to get rid of all resistance arising from dragging propellers and stern-posts of a bad form through the water—which caused a loss equal to the cube of the velocity of resistance to a body passing through the water.

Mr. HUMPHRYS said he had accompanied Mr. Dinnen when the experiments with the 'Desperate' were made. Those experiments extended over a period of fourteen days, and it was unnecessary to say, that they had been accurately recorded, so far as the speed of the ship was concerned.

During the time that Mr. Humphrys held the appointment of Chief Engineer at the Woolwich Dockyard, he had many opportunities of measuring the power expended in propelling different vessels, at different velocities. Trials with the 'Retribution' paddle-wheel steamer, of 1,800 tons burthen, in July, 1850, showed that with four boilers, and 1,092 indicated H.P., a speed of 10·4 knots per hour was attained, whilst with one boiler, worked at the highest grade of expansion, and 226 indicated H.P., the speed was 6·22 knots. These results agreed very nearly with what would be deduced from the usually accepted rule. With a totally different class of vessel, the 'Onyx,' one of the paddle-wheel mail boats between Dover and Calais, with two boilers, worked to full power, and 533 indicated H.P., a speed of 13·16 knots per hour was realised; whilst with one boiler, and the steam at a low pressure, the indicated power was 158 H.P., and the speed was 8·6 knots. This, when worked out, still went to support the recognised theory. He might also mention the case of H.M.S. 'Desperate,' a screw-steamer, before referred to, which was tried in the River Thames, before being sent out to sea. With four cylinders, a speed of 10·76 knots was attained, with 891 indicated H.P.; whilst with two cylinders, the speed realised was 8·78 knots, with 391 indicated H.P.

The Author appeared to base his arguments, in a great measure, upon the reports of the trials of the French war-steamer 'Charlemagne,' in which the expenditure of coal, with two boilers, was 3,064 lbs., to propel the vessel at the rate of 8 miles an hour, and 5,733 lbs., when the speed was 10·9 miles per hour. He then proceeded to measure the power by the quantity of coals burnt. This, Mr. Humphrys believed, was very fallacious reasoning, as the quantity of coal burnt could not be taken as any index of the power exerted by the engines, unless they were working under precisely similar circumstances, which was not the case on board the 'Charlemagne.' During the trials with the 'Retribution,' before referred to, two sets of indicator diagrams were taken. Diagram Fig. 1 would be looked upon as a fair average expansion card. Diagram Fig. 2 indicated the state of the engines when working at

Fig. 1.

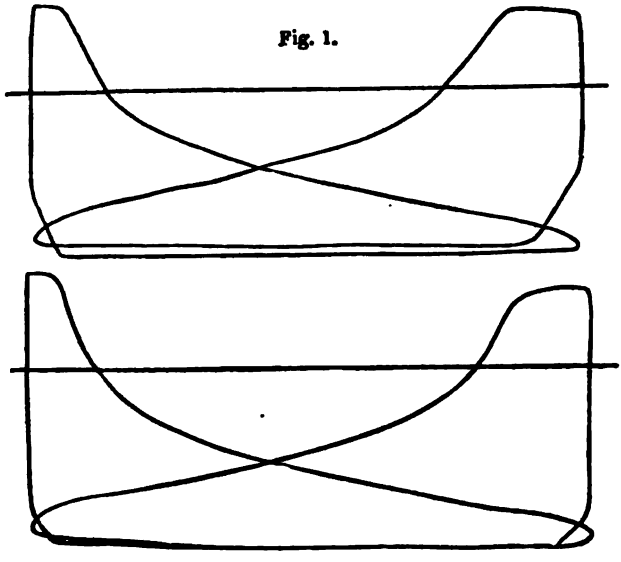
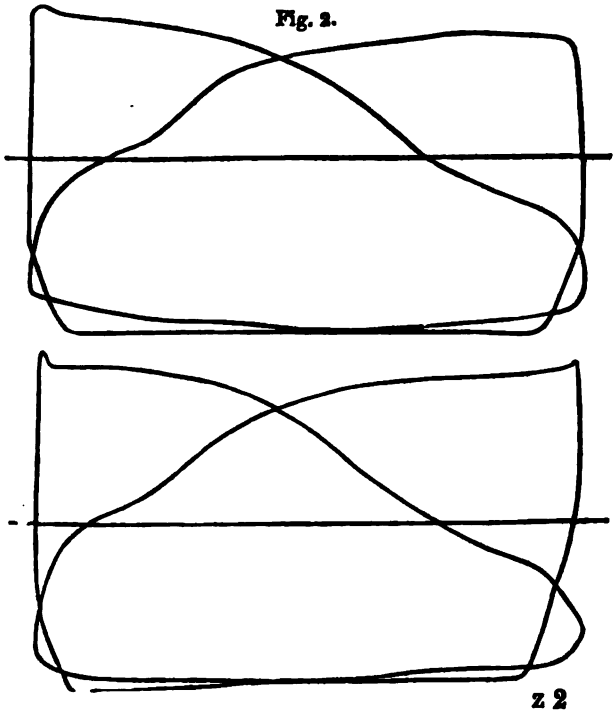


Fig. 2.



full power. In the former the quantity of steam used, measured by the diagram, was 6½ cubic feet per minute, for each indicated H.P., and in the other, where as much steam was put into the engines as was desirable, it was 11 cubic feet, both being taken at atmospheric pressure. Yet, the boiler surface, in the former case, was 7·2 superficial feet, whilst in the latter, it was only 5·96 superficial feet, per indicated H.P., so that, taking the boiler surface as an index of the steam generated, there was a loss of fully 50 per cent. He would add, that fully nine-tenths of the advantage, supposed to result from working steam expansively in marine engines, was due to the reduced expenditure of power. A trifling loss of speed in the ship was not noticed, and all the economy which resulted from the reduced expenditure of power was attributed to expansion. The results of the trials of the 'Desperate' supported this view. When four boilers and four engines were worked, 5 lbs. of coal were burnt per indicated H.P. per hour: whilst with two boilers working the four engines expansively, 8 lbs. of coal were burnt per indicated H.P. per hour.

Mr. SAMUDA would offer a few observations, with the view of removing the impression which appeared to be entertained, that form had nothing to do with the speed of a vessel through the water. The 'Dart,' a London and Margate steam-boat, which was originally constructed like a sailing-ship, after running for some time, had a new bow added, by which, without any alteration in the engines, entirely in consequence of the reduction of resistance, her speed was improved at least 10 per cent. A better result was obtained, shortly afterwards, in the 'Magnet.' The original bow was at an angle of 42°, and in this state she had 134 feet of midship section immersed; when the angle of the bow was altered to 23°, she had 135 feet immersed. The speed in the former case was 10·02 knots, and in the second 11·75 knots an hour, being an increase in the ratio of performance of nearly 30 per cent. Another instance, still more marked, occurred last year, in a vessel called the 'Flying Fish'—one of the larger class of Government despatch boats. This vessel, with 1,166 indicated H.P. only attained a speed of 11·73 knots. That performance did not equal the expectations of the Admiralty authorities: and, without any variation in the other parts of the vessel, they added, not a new bow, but an elongated bow, 18 feet in length, in advance of the original one, to divide the water more freely. The result was, that with the same draught of water, an increase of velocity from 11·73 knots to 12·55 knots an hour was attained. The indicated H.P. was 100 H.P. more, but making all allowances for that, the ratio of performance was increased as 7 to 6. The 100 additional indicated H.P. would not advance the velocity of the ship more than one-tenth of a

knot per hour, whereas the increase of speed was eight-tenths, showing seven-tenths as due to lessening the resistance. The screw, in fact, became a better propeller, and the decreased slip (in the improved performance) was exactly seven-tenths of a knot. He thought these facts were sufficient to remove the impression, that form had nothing whatever to do with the speed of a ship.

With regard to the question of the cube of the velocity being the real measure of the resistance, an examination of forty, or fifty vessels had induced the conviction, that there was no other way of measuring it. There was a point assumed in the Tables prepared by the Author of the Paper, which, if taken as a starting-point in the discussion, would lead to error, if the facts were dealt with by the same law. Every vessel in the Table was treated, as if the same coefficient applied to all forms and kinds of vessels. Now, it was well known, that for every vessel, a different coefficient was necessary. Thus, for H.M. Yacht the 'Fairy,' the coefficient was about 700, whilst for the 'Himalaya' it was 1,200, and yet these two had been treated by the Author as identical. Experience had shown, in all cases, that the resistance was nearly as the cube of the velocity, and that when a proper coefficient was adopted the speed might readily be calculated to within a quarter of a knot. Some experiments with four vessels, built on the same lines, although at different periods, and without any intention of comparison, yet agreed in a remarkable degree. The particulars of these vessels might be thus given:

No.	Midship Section.	Indicated H.P.	Miles per Hour.
	Sq. Ft.		
1	266	226	10·2
2	248	220	9·7
3	190	213	10·5
4	190	320	11·6

This showed, very nearly, the same ratio of performance throughout, and the vessel which had the highest velocity had the greatest amount of immersion, the screw working more efficiently.

Mr. RENNIE said, a comparison of the actual speed of two ships belonging to the Peninsular and Oriental Company, the 'Candia' and the 'Pera,' with the speeds calculated by two of the rules given in the course of the discussion, showed the following results:—

	CANDIA.				PERA.			
			ERROR.				ERROR.	
	Knots.	Statute miles.	Knots.	Statute miles.	Knots.	Statute miles.	Knots.	Statute miles.
Speed, Actual	11·93	13·7	..	..	12·55	14·4	..	..
Ditto by formula $V^3 = \frac{\sqrt{\text{H.P.} \times c}}{D^3}$	11·38	13·1	·55	·6	11·22	12·9	1·33	1·5
Ditto ditto $V^3 = \frac{\frac{2}{3}\text{I.H.P.} \times 100}{\text{Mid. Sect.}}$	11·28	13·0	·65	·7	11·28	13·0	1·27	1·4

The dimensions of the 'Candia' were, length 281 feet, breadth 40 feet, and depth 29 feet 6¾ inches. The engines were 450 nominal H.P. and 1,340 indicated H.P. The mean draught was 18 feet 4 inches, the area of the midship section was 523 square feet, and the displacement was 2,422 tons. The dimensions of the 'Pera' were, length 303 feet, breadth 42 feet, and depth 29 feet. The engines were 450 nominal H.P., and 1,414 indicated H.P. The mean draught was 18 feet 3 inches, the area of the midship section was 552 square feet, and the displacement was 2,792 tons.[1]

Mr. G. P. BIDDER, V. P., said, it had been determined by mathematicians of the highest standing, that the resistance was as the square, and the power as the cube; and it was, therefore, useless to discuss, whether the actual friction was as the square of the velocity, and whether the resistance to a body moving in water was also as the square. The theory of rivers, and the movement of water in pipes, both showed, that allowance must be made for the

[1] The results of the trials of the 'Candia,' when first tested, and after being lengthened, subsequent to the discussion, 33 feet 6 inches amidships, by which the load displacement was increased about 470 tons, was conclusive as to the effect of lengthening:—

Date of Trial.	Draft of Water.	Length.	Displacement.	Weight on Board.	Revolutions of Engines.	Pressure of Steam.	Vacuum.	Indicated H.P.	Pitch of Screw.	Number of Blades.	Speed of Vessel.
1854: May 31.	18·6	281	2,520	650	36½	22	26½	1,672	20	2	12·651
1857: Aug. 12.	19·0	314·6	3,090	1,000	33	20	26	1,462	21	3	12·443

Thus with rather less indicated power, the vessel made nearly the same speed as formerly; and had the boilers been new and indicated the same power, it was believed that her speed would have been equal to, or even greater than on the last occasion; proving that it was not merely the displacement that must be taken into account in comparing vessels, but also its disposition.—G. R.

resistance due to friction. He calculated that the 'Himalaya' had an immersed surface of 18,000 square feet, and that this, at a velocity of 13 knots to 15 knots per hour, would absorb 800 indicated H.P., supposing that the bottom was perfectly clean and free from barnacles, &c. It was easy to contrive a formula which should give results nearly agreeing with the actual facts, at some one point over a long range of figures; and the error was less apparent, when the actual and calculated velocities were compared, than when the power was taken into account, as a variation of only 7 or 8 per cent. in the former case would cause a difference in the latter of 25, or 30 per cent. Nothing required greater care, knowledge, and skill, than the conduct of experiments on the friction of bodies moving in water. A large series of experiments of this kind, which had gained for their Author admission into the Royal Society, had been found to be incapable of analysis. The size of the vessel, and particularly its length, were undoubtedly of great importance for ocean navigation, as the vessel then acquired sufficient momentum to overcome the irregularities and undulations of the surface of the sea, which it must encounter.

PROFESSOR AIRY said, that many of his views on this subject had been anticipated in the discussion which had already taken place. He was much struck with the dangerous tendency of the experiments detailed in the Paper. In experiments to ascertain the resistance of bodies passing through fluids, and the amount of steam-power necessary to overcome that resistance, it was proper to separate the different parts of the experiment, and to confine one experiment to the variations of one element alone. He believed, that, up to the present time, there had not been a sufficient number of experiments to determine accurately, for the ordinary velocities of steam-ships, the relation of the resistance to the velocity of the ship; and he was confident, that anything which the Institution of Civil Engineers could do, to promote experiments with regard to the power of traction, (as shown, for instance, by a dynamometer on a tow-rope,) in relation to the speed with which the ship was drawn through the water, without any reference to the power of the steam-engine, or the consumption of coal, would be of the utmost value to practical science. There was a positive, mathematical, invariable relation between the resistance, and the power required to overcome that resistance; that was, if the law of resistance could be made out, as shown by the tension of a rope, and could be expressed by an algebraical formula, that formula must be multiplied by the velocity, in order to express the law of the power necessary to overcome that resistance. For instance, if the resistance was proportional, exactly, to the square of the velocity, the power necessary to overcome that resistance was exactly proportional to the cube of the velocity. That was a mathematical truth not admitting of the smallest modification. Whether the steam-engine

was properly adapted to produce this power, and whether the consumption of coals was properly managed, were totally different questions, and were each the subject of different experiments; but, considering the complication of each of these questions, they ought never to be combined in one set of experiments. With regard to the screw, he might mention an idea which occurred to him some years ago, as tending, possibly, if followed out, to throw some light on the subject of the loss of power in the use of the screw, and the way in which that loss might be reduced. He took it for granted, that where a screw was used as the propelling power of a ship, there were three classes of loss of power; two of these were "slip" of different kinds, because the screw did not hold its place as if water were a solid element, like the wheels of a locomotive upon a railway; a third was the friction of the screw in the water. With regard to the slip of the fans of the screw in the water, if the different action of the screw, at different degrees of pitch, was considered, it would be found, that when the pitch was very low, the slip might be considered as mainly in a longitudinal direction of the spindle; and where the pitch was high, the slip was occasioned mainly by the water being carried in rotation. Hence it appeared to him, that something might be gained by obtaining a correct knowledge of the degree of motion given to the water in the two following cases:—one with such fans, as, when turned in the water, would not produce any endways motion—fans whose planes all passed through the line of the axis; and the other, in which there was not rotation, as when a disc surface was moved in the direction of the spindle. These might be taken as the extreme cases of the two degrees of slip which were combined in the screw—the one a rotary, and the other a longitudinal slip. But there was another circumstance, probably not inconsiderable in affecting the efficiency of the screw, as compared with the paddle-wheel; that was, the friction of the screw through the water. Considering the great speed at which the screw was turned, he thought that the friction through the water had considerable influence upon its power, and there was nothing analogous to it in the loss of power of the paddle-wheel.

Mr. GRIFFITHS said, the trials with the 'Flying Fish' at Portsmouth, showed that the form of the ship ought to be made suitable to the power intended to be applied. When tried on the 3rd of July, the following results were obtained:—

	Revolutions per minute.	Indicated H.P.	Speed in knots.
With full power . . .	74½	1106·06	11·603
„ ¾ „ . . .	69½	877·00	11·201
„ ½ „ . . .	59	576·00	9·923

Thus, when the power was doubled, there was only an increase of speed of 1·68 knot. She was then fitted with a temporary bow, to give a finer entrance, and again tried on the 16th of September, with the following results:—

	Revolutions per minute.	Indicated H.P.	Speed in knots.
With full power . . .	77	1309·00	12·572
„ ¾ „ . . .	68	918·72	11·150
„ ½ „ . . .	60	660·18	10·120

Thus doubling the power gave an increase of speed of 2·452 knots, or just what was due to the cube of the extra power exerted, with the temporary bow, whilst no increase of speed was obtained at half and three-quarter power, and at full power nearly 1 knot extra was obtained.

In these trials it was proved, that there was considerably more resistance offered by the water to the blades of a screw, when set at an inclination towards the ship, than when at right angles with the screw shaft. The screw of the 'Flying Fish' had two sets of blades, one set being at right angles with the shaft, in the ordinary way, and the other at an angle of about 18° to the ship. In the first case the pitch was 20 feet 6 inches, the number of revolutions 75½ per minute, and the indicated H.P. 1281·8; whilst in the latter, the pitch was only 16 feet, the number of revolutions 77·3 per minute, and the indicated H.P. 1265, giving a result slightly in favour of straight blades. The steam-ship 'Dane,' of 40 H.P. and 500 tons measurement, had originally a screw of 10 feet 6 inches diameter, and 18 feet pitch, with three blades, each 3 feet 4 inches wide at the point, and 1 foot 10 inches at the root, when the speed obtained was 8·5 knots per hour. When a screw with two blades was applied, of the same diameter and pitch, but the points only 9 inches wide, and 3 feet at the root, the speed was 8·675 knots, all the circumstances being alike, excepting that the two-bladed screw made 6 revolutions per minute more,—partly due to the diminished friction and to the increased speed of the vessel. The screw of the steam-ship 'Augusta,' of 60 H.P., was 5 feet 6 inches diameter, and was originally 11 feet 3 inches pitch, when the number of revolutions was 110, and the speed was 6·385 knots. When the pitch was altered to 10 feet 3 inches, the speed was increased to 7·9 knots, the number of revolutions, and all the other circumstances, being the same.

Mr. J. E. M'Connell remarked, that no conclusion could be arrived at either from the Paper, or from the discussion upon it, as far as it had yet gone; nor had an exact rule, or reliable data

of any description been produced, for the information and guidance of the Members. Great difference of opinion had been expressed, and the formulæ brought forward, for ascertaining the effect of certain proportions of vessels, and the relative forces necessary to propel them, at stated speeds, gave such different results, that it really seemed as if those who laid claim to a practical knowledge of the subject were incompetent to give any good rule, for determining the relative proportion of any one of the conditions of a steam-vessel. It was remarkable, that in a country which stood pre-eminent for its advancement in mechanical science, the application of steam to navigation was, as yet, imperfectly understood. As had been well remarked, what was required was, the proportion of the power disintegrated, that showing the amount used in propelling the vessel, expended in slip, by paddle, or by screw, and absorbed by the engines themselves. He quite agreed in the opinion, that the trials over the measured mile were of no value, either in point of comparative performance, or in consumption of fuel. He therefore proposed to direct attention to the results of the regular working of the Chester and Holyhead Railway Company's steam-vessels, running between Holyhead and Kingstown, a distance of 63 miles.

There were three vessels, named respectively the 'Anglia,' the 'Cambria,' and the 'Scotia.' They were built for speed; and, he believed that, when ordered, the builders of the ships and the makers of the engines were given to understand, that a test of their comparative merits, as to speed and economy of fuel, would be strictly applied. The arrangement for working these vessels was, that the time for performing the passage should be a constant, or as nearly uniform as possible; and that the variation of wind and tide should be met by more, or less pressure, the engines being worked expansively. The officers were subjected to censure, if the proper time was not kept, and the cause had to be fully explained.

The results of these trials were given in the annexed Table, which had been prepared by Admiral Moorsom, one of the Directors of the Chester and Holyhead Railway Company, to whom the excellent arrangements connected with the management of these vessels were due.[1]

He had been very anxious to elicit, from practical experience of these and other steam-ships at sea, some rule, or formula, by which could be determined the best proportions and forms of vessels, and the amount of power required to perform stated speeds.

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[1] *Vide* "Some Considerations on the Performances of Steam-Vessels." By Rear-Admiral Moorsom. Billing, Birmingham, 1856.

TABLE A.—Summary of Returns, showing the Performance of the Chester and Holyhead Company's Steam-vessels 'Anglia,' 'Cambria,' and 'Scotia,' and the Consumption of Coal between Holyhead and Kingstown, under certain conditions taken as standard tests.

Vessel's Name.	Time of Passage, 63 Statute Miles.	Rate per Hour, Statute Miles.	Proportion of Steam in Cylinder.	Vacuum by Diagram.	Pressure. By Diagram, per Sq. Inch.	Pressure. In Boiler, per Sq. Inch.	Barometer.	Hydrometrical Index.	Indicator H. P., 2 lbs. per Square Inch being deducted for Friction.	Coal Consumed in Running only. Per Trip.	Coal Consumed in Running only. Per Hour.
	h. m.			Inches.	lbs.	lbs.	Inches.			tons. cwts.	tons. cwts.
Anglia	4 10	15·1	11/32 of Stroke	10·75	8·52	13·5	25·5	1·6	866·25	11 3·5	
	4 2	15·6									
	4 12	15	11/32 of Stroke	10·89	7·40	13·37	25·25	1·6	804·94	9 18·5	
	4 8	15·24									
	4 23	14·33	29/32 of Stroke	10·67	7·17	13·5	25·	1·57	776·39	9 7·5	
	4 27	14·15									
Mean average	4 15	14·9		10·77	7·69	13·45	25·10		815·86	10 3·1	2 7·9
Cambria	4 10	15·1	17/32 of Stroke	10·34	9·81	14·62	24·62	1·25 to 1	1114·47	12 9·5	
	4 19	14·59									
	4 12	15	23/32 of Stroke	10·97	7·43	14·87	26·62		969·73	9 10	
	4 16	14·76									
	4 16	14·76	13/32 of Stroke	10·94	5·05	14·75	26·75		795·99	8 9	
	4 24	14·31									
Mean average	4 16	14·75		10·75	7·43	14·74	25·99		960·06	10 2·8	2 10·1
Scotia	4 4	15·49	21/32 of Stroke	10·7	7·87	11·33	26·5	1·82	1008·35	11 8·5	
	4 0	15·75									
	4 0	15·75	23/32 of Stroke	11·12	6·35	10·75	26·75	1·8	951·23	9 8·5	
	4 0	15·75									
	4 5	15·40	15/32 of Stroke	10·85	5·17	12	26·5	1·8	821·45	8 17	
	4 0	15·75									
Mean average	4 1·5	15·64		10·89	6·46	11·36	26·58		927	9 18	2 6·6

The pamphlet by Admiral Moorsom, entitled 'Considerations on the Performances of Steam Vessels,' which had been printed for private circulation, bore so closely on the subject, that, with permission, he would make a few extracts from it.

The Admiral first remarked that, "one of the greatest obstacles to the scientific progress of naval architecture, is the absence of accurate observations at sea, that is, under the actual circumstances of vessels at their ordinary work."

Further he said, "The present incomplete position of the science of naval architecture has been brought especially under my notice lately, in consequence of proposals made by Government for the improvement of the mail and passenger communication between London and Dublin. It is proposed, that the passage between Holyhead and Kingstown should be made in three hours, between the lighthouses, a distance of 63 statute miles, and therefore at a speed made good of 21 miles an hour. At the request of the Companies to whom the proposals were made, certain firms offered to build vessels suited for the service. The vessels proposed, differed in displacement from about 1,550 tons to above 3,000 tons; in nominal horse-power from 550 to 1,600 tons; in ratio of breadth to length, from 9·37 to 11·6 per cent.; in draught of water to breadth, from 30 to 40 per cent.; and in maximum speed to be attained in smooth water, from 22 to 25 miles an hour. Such varieties in a case apparently so simple, involving one condition only, namely, speed, illustrate clearly the want of rules founded on actual performance at sea. The question at issue is not the stowing of cargo, or of a large amount of fuel, or of carrying an armament, or of accommodation for a great number of persons, together with the accomplishment of a given speed: but of speed specially and alone, with as easy a motion in a seaway as the case admits of; for whatever the size may be that the speed requires, that size must be more than large enough for any probable amount of passengers under the circumstances."

With these great diversities in practice, it certainly did appear that something ought to be done, in order to obtain some reliable data on which to proceed. The suggestion, that the Government and the steam navigation companies should be requested to carry out a series of experiments at sea, was excellent, and would be productive of very beneficial effects, if there was a careful record of the performances, an exact compilation of them, and an honest publication of the recorded facts. It had occurred to him, that such experiments might be made with vessels like those belonging to the 'Cunard' and 'Collins' lines, running between Liverpool and New York.

The average consumption of coal on board the Holyhead steamers, for six years, including 1855, was at the rate of 5 cwt.

per hour under that given in Table A (page 347). The consumption during 1849 was at the rate of 2 tons 15 cwt. 98 lbs. per hour; but by the system subsequently introduced by Admiral Moorsom, a saving had been effected at the rate of 12 cwt. 60 lbs. per hour. It was carrying out on the passage between Holyhead and Kingstown, a system of comparison amongst steam-vessels, like that in use amongst railway locomotive engines, namely, the comparative amount of work done and of fuel consumed, for after all the chief point to be considered, was the economy of fuel, and the service performed. Quoting again from the Admiral's pamphlet:—

"Among the experiments made on the resistances to various forms of floating bodies, none are of more value than those of the late Colonel Beaufoy.

"Among those made to determine the performance of steam-vessels, the results established by MM. Bourgois and Moll are the most available for use. But the principle of Beaufoy's experiments is capable of a more extended application.

"The formula established by Bourgois and Moll, in 1848, and subsequently adopted in the paper printed by the Admiralty, in 1850, of which I have availed myself, and which records contain results of the trial of forty-four screw steamers, is useful so far as it gives a coefficient which is an exponent of the resistance offered by the form of the vessel, so long as the engines give out a relative uniform power.

"But as the 'absorbed power' varies in different engines, and in the same engines under different conditions, and as the 'slip' is affected by conditions of speed, and by the relative proportions of the wheel (or the screw), such a coefficient is not a measure of the resistance of the vessel under all circumstances, though it affords a fair medium of comparison of one vessel with another of equal displacement.

"This measure of the relative resistances of the same vessel under different conditions, or of different vessels under similar conditions, cannot be indicated by one coefficient only.

"Moreover, in the use of the formula in question, the value of the coefficient must, at present, be assumed arbitrarily at a guess in each case where it is required to determine the power, if the speed be given, or the speed, if the power be given; and it is only by collecting and classifying facts, in relation to different forms and sizes of vessels, and description of engines, that the application of the coefficient, in any given case, can be approximately reached.

"I am not aware that such collection and classification is yet commenced, except in private hands.

"I have been enabled, in some degree, to verify the experi-

ments of Beaufoy on the resistance due to the mid-section of vessels, and the proportion of that resistance experienced by different forms. The basis of this verification is the resistance measured by the weight of the column of sea-water, whose base is equal to the area of mid-section, and height equal to that from which a body must fall to acquire the speed at which the area is impelled.

"The resistances, within my observation, lie within 10 to 12 per cent. of that deducible from this law, and reach to about 15 statute miles an hour."

The Admiral alluded to a verification of Beaufoy's formula applying to vessels attaining the speed of 15 miles per hour, and he says that "It is of importance to the subject under consideration, but it is not easy, to separate the elements composing the resistance opposed to the pressure on the piston.

"This consists of the resistance due to the form of the vessel, the slip of the wheel (or screw), and the power absorbed by transmission of the motion. This latter again is composed of the friction of the unloaded engine, the additional friction thrown on it by the load, and the retardation of the piston arising from an imperfect vacuum; or, in the case of non-condensing engines, by the full pressure of the atmosphere. The slip may, strictly, be considered as a part of the absorbed power, but it is desirable to treat it as a distinct element."

The formula of Beaufoy was given, but would scarcely apply to the practice as shown.

Table B (page 351) gives the resistances of some vessels as calculated by Admiral Moorsom. "On this Table many questions may be raised and much controversy, but the practical questions are two:—

"1st. Are the ratios of the breadth to the perimeter of the water-line, and the sine to the cosine of the angle of incidence of the water on the fore-body, together, an approximate measure of the rate of resistance compared with that due to the mid-section?

"2nd. Is the ratio of breadth to perimeter an approximate measure of the relative rate of resistance due to the form of the vessel, compared with that due to the mid-section? And is the ratio of sine to cosine of the angle of incidence of the water on the fore-body an approximate measure of the rate of resistance represented by the slip and the absorbed power? If these questions are answered in the affirmative, the results in the Table necessarily follow."

In that Table the vessels were distinguished by the letters A, B, C, D, E, F, G, H. In vessel A the ratio of breadth to perimeter per cent. was 6·5: of sine to cosine of angle of incidence per cent.

TABLE B.

Name.	Load Water-line.							Ratios.				Proportions of Resistance.			Proportions of Power.			Actual Power on Piston in lbs.	Effective Power of Resistance.		Speed, Feet per Minute.			Difference of Calculated Speed per Cent.		Coefficient of Performance.	
	Length.	Breadth.	Draft.	Area of Mid-section.	Perimeter.	Angle of Entrance.	Displacement.	Breadth to Perimeter per Cent.	Sine to Cosine of Angle of Incidence per Cent.	Resistance compared with that due to Midsection. Calculated per Cent.	Resistance compared with that due to Midsection. Actual on Trial per Cent.	Due to Vessel per Cent.	Due to Slip per Cent.	Absorbed Power per Cent.	Due to Vessel per Cent.	Due to Slip per Cent.	Absorbed Power per Cent.		Calculated.	Actual on Trial.	Calculated.	Actual on Trial.	Actual at Sea.	+	−		
	ft.	ft.	ft.	sq. ft.	ft.	°	tons												lbs.	lbs.							
A	194	26·8	8·85	188	415	15·75	600	6·5	13·8	20·3	23	6·5	5·14	11·2	28·3	22·4	49·2	30182935	21270	23023	1372		1311	4·6		666·7	At sea.
B	198	27	9·5	230	422	15·5	750	6·4	13·6	20	22·5	6·4	4·9	11·24	28	21·79	49·8	35001630	26003	27027	1346		1295	3·9		689·2	
C	195	27·5	8·75	182	415	16	600	6·6	14	20·6	22·9	6·59	4·87	11·46	28·7	21·24	49·8	33863034	23730	24579	1427		1377·7	3·57		680·7	
D	300	40·25	13·75	393	638	15·26	1926	6·26	13·4	19·66	16	6·26	together 9·8 data wanting.		38·77	together 61·2 data wanting.		98340000	61416	87549	1601	1708·8			6·31	965·58	In smooth water.
E	144·6	21	4·83	71·5	308	16·5	168	6·8	14·5	21·3	21·17	6·8	7·36	7·5	32	34·6	33·25	12005400	8763	8876·5	1370	1352·56		1·2		713·6	
F	194·3	34·6	14·5	392	416	20	1323	8·3	17·84	26·14	21	8·3	3·34	9·33	39·3	16·4	44·2	30346800	30781	28737	986	1056			6·64	736·6	
G	210	40·5	15·25	517	451	22	2050	8·98	19·4	28·38	23·8	8·98	5·158	9·66	37·7	21·67	40·6	41091600	42774·8	44176·9	970	930·16		4·2		490·3	
H	176	48·5	21·3	750	390	31	2828	12·4	27·7	40·1	44	12·4	9·75	22	28	22	49·8	28997100	42800	44229	677·5	655·6		3·34		352·9	

13·8 : resistance compared to that due to mid-section 20·3 : actual on trial 23. The proportion of resistance due to the vessel was 6·5 per cent. ; that due to slip was 5·14 per cent., and the absorbed power was 11·2 per cent. ; this gave the whole resistance due to vessel, slip, and engines. That, as one instance, went far to show, that the formula laid down coincided very nearly with actual trial.

Mr. M'Connell was aware, that he was scarcely in order in reading such copious extracts ; but he thought, that on a purely scientific matter of this kind, when a new and very important formula was introduced, on so interesting a subject, the Author's views should not be slurred over. He had only taken selected portions of the pamphlet, which bore directly upon the subject of discussion.

In answer to questions from Members through the President relative to the formula, which did not appear to be given in the pamphlet, Mr. M'Connell said, the proportions of the breadth to the perimeter were given in the Table, as were also other conditions on which the calculations were based. The Table spoke for itself, and he was sure the meeting would not wish him to go through the whole calculation. As a starting point, there was Beaufoy's formula, on the resistance due to the mid-section of vessels ; and all engineers were, he believed, well acquainted with the formula which had been alluded to.

Mr. M'Connell observed, that in all discussions on this subject he had listened with great attention, hoping to obtain some practically useful data, or formulæ, but none were offered. He begged to suggest that Mr. Scott Russell should favour the Institution with his formulæ, and also that other ship-builders and engineers should do the same, as it was believed that they all differed from each other. Mr. M'Connell would then be ready to compare the formula he had advanced with theirs, in order to ascertain which was the best for general practical guidance.

Mr. J. Scott Russell stated, that the usual formula of Colonel Beaufoy, $R = a\, w \frac{v^2}{2g}$ only gave the resistance to a boat with a square head ; but what was wanted was the reduction upon this, for a certain amount of sharpness of bow, for different sizes, shapes, and proportions of vessels. With a semicircular or round head, which was nearer to the form of the bows of sailing ships, it had been found, that the resistance was only two-thirds of the amount derived from the above formula ; and with an elliptical head it was still less. Formerly the duck's breast had been regarded as the most beautiful form of bow, but, by making the bow finer, the resistance had been gradually brought down to one-fifth, one-sixth, and one-seventh of the total resistance given by the formula, as the result of a long course of experiments. He believed the quantity of engine power to propel a large vessel through the water was

now, in some cases, as low as one-twelfth; ship-builders having endeavoured, during the last twenty-five years, to diminish the coefficient by means of improved forms.

The theory in the Paper was, that the shape of a ship had nothing to do with the speed. He had an opportunity of trying this experiment, when he had built two vessels of nearly identical dimensions, to which he had given the same midship section. Both these vessels were 15 feet wide; one was 144 feet in length—the other 100 feet; one had 42 square feet of midship section—the other 43 square feet. Each vessel had engines whose cylinders were 30 inches diameter, and 2 feet 6 inches stroke, each having developed exactly the same amount of power. The one which attained the greatest speed made 36 revolutions per minute, whilst the other made 38 strokes, and yet the vessel was propelled at a slower rate. The result was, that one vessel had a speed of 10·08 knots per hour, whilst the other attained a speed of only 8·88 knots. In this case displacement, midship section, and everything were similar, excepting form and length, and these caused the difference in the performances. But it might be said, that the difference was accounted for by the difference of length, and such had been his opinion also; therefore he determined to make a second experiment upon two vessels of nearly identical length. These two vessels were built of the respective lengths of 190 feet and 186 feet, their breadths being equal: the engines had cylinders of 48 inches diameter, with 4 feet 6 inches stroke. One engine made steadily 39 strokes per minute—the other from 38 to 40 strokes. The speed attained by the former was 15·03 knots, whilst that of the latter was only 11·32 knots. The difference between the two vessels in this case consisted chiefly in the shape;—the other and minor elements being much in favour of the slower vessel; for instance, the faster vessel had 124 feet of midship section, whilst the slower vessel had only 71 feet of midship section, to drag through the water. The faster vessel drew 6 feet 8 inches of water, whilst the slower vessel drew only 2 feet 10 inches of water. In this case the difference of length was only 4 feet, yet a radical difference in shape only reduced the velocity, with equal power, from 15 knots to 11 knots per hour. In the case of a vessel built with bow and stern alike, so as to travel either way, when going with bows first, the speed was 10·88 knots, and when running the other way it was only 9·64 knots; this latter case was another criterion experiment on the effect of shape alone.

The ship-builders had been accused of not knowing their business; whilst it was said, that the engine-builders performed their part of the work perfectly. That comparison was most unjust to the ship-builders, who had made a vast number of useful experiments, had

devoted a great deal of pains and study to their profession, and had in reality got possession of nearly all the practical facts which they were accused of not knowing. The first step which a shipbuilder took before he constructed a vessel, was to find the area of the midship section (a in the formula). The influence of the midship area was this;—an engine in a ship was required to make the hole in the water through which the ship had to pass, which might be compared to the excavation of a long canal. The first calculation then was, how large a canal the ship was required to open for itself—how much water it had to displace? The next question was—how much power had the engine to exert to displace this water from its path? Then $\frac{v^2}{2g}$ was the measure of this power, and w being the weight of water an inch in depth, the total weight of water was equal to $a \frac{v^2}{2g} w$. This well-known formula went no farther; it omitted the one element which all the formulæ he had hitherto seen also left out, and which he had hoped Admiral Moorsom's pamphlet would have given. That was the reduction, necessary for a certain degree of fineness of shape. But almost all shipbuilders, in calculating the resistance which their vessels opposed to the water, only took a fraction of the result derived from the formula.

He agreed in the suggestion of making exact experiments, on a large scale, to ascertain the value of this fraction in ships of different forms. He ventured to repeat the hope, that the Council would not think it inconsistent with their duty to the profession to endeavour to get a few good, reliable, practical results, showing the value of this fraction for different sizes, shapes, and proportions of vessels. He had made most of these experiments, and on some future occasion he should be happy to communicate them to the Institution.

For the present he would content himself with saying, that he had ascertained, that at 10 knots per hour, with a vessel of proper form, of 1,500 tons burthen, the head resistance of a ship could be reduced to 50 lbs. per square foot. He had also ascertained how much a similar vessel could be propelled with by engine power alone, including the loss due to the working of the engines, and he had found that, whilst the direct resistance to a ship going at 10 knots per hour was only 50 lbs. per square foot of midship section, including all loss from communication by paddle-wheel, air-pump, and other sources, except the slip, this resistance was not more than 65 lbs. per square foot of midship section. Thus they could calculate confidently, to within a quarter of a knot, as he had done for years past with his peculiar shape of ship, the amount of steam-power necessary to propel a given ship, at a given speed, and there

was a shape for every speed; as for instance when a speed of 10 knots per hour was desired, he provided for 50 lbs.[1] per square foot of midship section, for the resistance of that ship, and when he had to overcome the resistance of the machinery also, he made that up to 65 lbs.[1] per square foot. These were the principles upon which he calculated. Perhaps the experience of other ship-builders led them to different results, which he should be happy to learn during this discussion. Though experimenting in that way, the ship-builders would still be thankful to those who could give them information. But while he confessed they did not know all that they desired, he did not thereby plead guilty to their knowing nothing at all upon the subject.

Mr. HAWKSLEY stated, it was quite possible, in the present advanced state of hydraulic science, to calculate with any desirable degree of accuracy, the value of the resistance which a steam, or other vessel would have to overcome, when moving through water at any given speed. The resistance consisted of two parts; the one well recognised under the somewhat obscure title of "the resistance to the immersed area of the midship section;" the other as yet scarcely admitted, though not less important, might be designated "the surface, or frictional resistance."

The midship resistance, considered without reference to the angular figure of the bow, or stern, was manifestly measured by the impulse of a stream of water having the velocity of the vessel upon a plane surface placed perpendicular to its path. This impulse was found, by experiment, to vary under different circumstances, from a value equal to the pressure of a column of water of twice the height due to the acquired velocity, down to a value equal to the height due to the acquired velocity. The latter measure would most probably apply to the resistance encountered by a sea-going steamer.[2]

Now, taking the area (a) of the midship section in square feet, the velocity (v) of the vessel, in lineal feet per second, g the accelerating force of gravity = $32\frac{1}{6}$, and the weight of a cubic foot of sea water at $64\frac{1}{3}$ lbs. avoirdupois, and calling the resulting pressure (P), there was given,

$$P = \frac{v^2}{2g} a \times 64\tfrac{1}{3} = v^2 a.$$

The surface resistance of water moving in contact with iron he

[1] These figures, 50 lbs. and 65 lbs., are *gross* resistance, and include friction of skin. If friction of skin be deducted from these results, the remainder due to midship section comes down to about 25 lbs. *nett*, or $\frac{1}{13} a \frac{v^2}{2g} w$; *i. e.* $\frac{n}{m} = \frac{1}{13}$, being a difference of 6 to 1 in favour of the shape Mr. Russell used, over the old circular bow.—J. S. R.

[2] *Vide* Experiments of the French Academicians.

had ascertained with great care, and had found it amount to 25 ounces per square foot, with a velocity of 15 feet per second, whence, as this resistance varied exactly as the square of the velocity, it was very easy to calculate the retarding pressure (p) in lbs. of which it was the cause, when operating upon any area (s) of immersed surface by the very simple formula,

$$p = \frac{25}{16}\left(\frac{v}{15}\right)^2 s = \frac{v^2}{144}\, s.$$

But the value of (P) was modified by the respective angles made by the bow and the stern; calling the former (θ) and the latter (θ_1), then

$$P = \frac{1}{2}\, v^2\, a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right).^1$$

The total resistance R to motion was therefore

$$P + p = R = \frac{1}{2}\, v^2\, a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + \frac{v^2}{144}\, s.$$

And if, as very commonly happened, the velocity (V) was given in statute miles per hour, there would be obtained by making

$$v = \frac{5280}{3600}\, V = \frac{22}{15}\, V,$$

$$R = 1{\cdot}08\, V^2\, a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + \frac{V^2}{67}\, s.$$

Moreover, if it was desired to know the effective horses power (H) requisite to overcome this aggregate resistance, there was deduced first

$$\frac{5280\ R\, V}{60 \times 33000} = \frac{R\, V}{375},$$

and thence

$$H = V^3 \left\{\frac{a}{347}\left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + \frac{s}{25125}\right\} \text{ - - - A}$$

Also similarly

$$V = 29 \left(\frac{H}{72\ a \left(\sin^2 \frac{\theta}{2} + \sin^2 \frac{\theta_1}{2}\right) + s.}\right)^{\frac{1}{3}} \text{ - - - B}$$

Mr. Hawksley further stated, that in these terms the formulæ

[1] Theory assigns to the resistance of a moving plane inclined to its path at any angle θ the ratio of sin. $^2\theta$; experiment on the contrary affords a much higher result. It must, however, be remembered that experimental results have hitherto been complicated with the resistances arising from surface friction and the friction of the apparatus employed. This equation is capable of being expressed in another form, in which the second term within the paranthesis becomes negative, and corresponds to the minus pressure of some authorities.—T. H.

had been repeatedly compared with the actual performances of sea-going vessels of known power, magnitude, and figure, and so far as his experience had yet gone, it enabled him to place his deductions before the Institution with perfect confidence in their general accuracy and practical applicability. He thought that the formulæ would, in point of fact, afford results within 5 per cent. of actual experience. He also considered it was quite useless to attempt equations for curved forms, nor was it necessary to do so, as by dividing the immersed solid into four parts, by five equidistant planes taken parallel to the load water line, and calculating each part for three, or more angles, formed by the intersection of tangents to the respective curves of the bow and the stern lines, any required degree of exactitude might be obtained. In general, with regard to sharp vessels, a single calculation would be sufficient for ordinary practical purposes, and especially so after a little experience had been gained in estimating the angles at the head and stern capable of approximating to the results of curves.

In applying the formulæ, it was however requisite to bear in mind, that the effective horses power was in the case of large vessels about one-fifth part less than the indicated horses power, and also that in fresh water the resistance was somewhat less than in sea water, except in the case of confined channels, when it became greater than in the open sea.

Suppose it were wished to predetermine the speed of a vessel of nearly the magnitude and power of the 'Atrato,' and laid down on the following data:—

Indicated horse-power . . .	=	3000
Effective horse-power = $\frac{4}{5}$ths indicated H.P.	=	2400
Beam	=	40 feet.
Immersion ($\frac{2}{5}$ths of beam) . .	=	16 „
Midship section	=	512 „
Slant length of bow to beam[1] . .	=	$2\frac{1}{2}$: 1
Midship length to beam . . .	=	$2\frac{1}{2}$: 1
Slant length aft to beam[1] . . .	=	3 : 1
Total length to beam . . .	=	8 : 1
Surface (assumed)	=	12800 feet.

$$\text{Then } V = 29\left(\frac{2400}{72 \times 512 \times \left(\frac{1}{25} + \frac{1}{36}\right) + 12800}\right)^{\frac{1}{3}} = 15\tfrac{2}{3}$$

miles per hour. The 'Atrato' was stated by the Author of the Paper to have attained in fresh water a velocity of 16 statute miles per hour over the measured mile.

Again, given with the same general proportions, a beam of 80

[1] The Slant length may be taken to be the length in contact with water.—T. H.

feet and a required speed of 18 miles per hour, to find the effective horse-power. In this case

$$H = 18^3 \left\{ \frac{2560}{347} \left(\frac{1}{25} + \frac{1}{36} \right) + \frac{51200}{25125} \right\} = 14{,}327 = \text{the}$$

effective H.P., or about 4500 nominal H.P.; but if the speed were to be reduced to 15 miles per hour, then the effective horse-power need not exceed 8264, or about 2500 nominal H.P., estimated at a mean of the present irregular, uncertain, and inconstant practice of computing the nominal capability.

The formulæ also showed, that the employment of an excessive length, or sharpness of bow was in most instances to be deprecated, and especially so where the stowage of cargo, or even the stowage of a large quantity of coals for a long voyage was an important object, for it must be obvious, that in many instances, the surface resistance, represented by the second term of the equation, might increase faster than the midship resistance represented by the first term of the equation, diminished, and indeed, in the example before the meeting, it would be found, that the surface resistance (a resistance which had hitherto been little cared for), was enormously greater than the midship resistance; indeed in many instances, this resistance was three, four, and even five times greater than the midship resistance.[1] The equation, also, pointed very distinctly to the value of magnitude. In vessels of a similar figure the amount of cargo stowed would be as the cube of the square root of the midship section, or as $a^{\frac{3}{2}}$, while the surface and midship resistances would each be as a only. The enormous expense attending high speeds was also indicated, as both descriptions of resistance involved the employment of a mechanical power, increasing as the cube of the maximum velocity, and an expenditure of fuel, increasing as the square of the velocity to be maintained in the transit between any two given ports. Hence the economy of steam navigation was dependent mainly on four elements,—

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[1] It is worthy of observation, that as respects sharp vessels the speed may be approximately determined, without any direct regard to the midship section, by the very simple formula $V = 27\left(\frac{H}{s}\right)^{\frac{1}{3}}$; and as ($s$) frequently approaches the rectangle of the breadth (b) and the length (l), this becomes (approximately) $V = 27\left(\frac{H}{bl}\right)^{\frac{1}{3}}$, and therefore roughly $H = \frac{V^3\, bl}{20{,}000}$. Thus if a sharply-built channel steamer be 200 feet long and 30 feet broad, and have two engines each of 60 nominal H.P., the total indicated power being about 500 horses, and the real, or effective power being about 400 horses, then, because $27\left(\frac{400}{30 \times 200}\right)^{\frac{1}{3}} = V$, a speed of about 11 statute miles per hour may be anticipated.—T. H.

1st. A sharp, but not excessively fine, entrance and run.
2nd. A moderate speed, regard being of course had to the special requirements of the service.
3rd. A considerable magnitude.
4th. A clean bottom, because the quantity s must be increased by an addition of the surfaces presented by weeds, barnacles, and other adhering substances.

Nothing had yet been said of the rules which ought to regulate the form of the after part of the vessel. It was, however, plain that as the same laws governed both the escape and the return of the water, the after part of the vessel should, so far as regarded the immersed portion, be as nearly as other more important considerations would permit, a duplicate of the bow, when the entrance was properly formed. But it was not necessary, except as a matter of taste, to employ complicated curves of contrary curvature in constructing the entrance and the run; indeed, in a long vessel, the lines of the bow and run might be, for considerable lengths, perfectly straight and tending very distinctly to the angles θ and θ_1, and these lines might be rounded off at each end with circular arcs of contrary curvature, without thereby sensibly affecting the performance of the vessel. It was also obvious, that the best way of obtaining both length and capacity, with a minimum resistance, was by the insertion of a parallel, or nearly parallel, piece in the middle of the vessel. It might likewise be remarked, that those lines which were considered to confer the greatest amount of beauty upon a vessel's hull, were all near approximations to the lines which would result from the intelligent study of the formulæ; and it might be further observed, that as regarded the power and speed of a vessel, it was by no means objectionable to employ a transverse section approaching to a rectangle, thereby obtaining a capacious hold, great buoyancy, and much stability. In strict theory the bow and stern lines of a vessel ought to be each formed of two equal and contrary parabolas, having a common tangent at their points of junction, and their vertices at the bow, the stern, and amidships respectively, but in practice considerable departures from the theoretical law might be made, without affecting the performance of the vessel in any very appreciable degree.

If a naval constructor wished to be particularly safe, with respect to the amount of power to be put on board, Mr. Hawksley would recommend the substitution of $\frac{a}{174}$ for $\frac{a}{347}$, in the formula A; and if anxious not to overstate the velocity, the substitution of 144 a for 72 a in the formula B. These altered terms, however, represented the most extreme values which any theory, or any experiment had assigned to the midship resistance; and after all did not,

in ordinary cases vary the resulting velocity so much as a twentieth part.

Mr. PHIPPS could not concur in the assumption, that the resistance per square foot in the interior of a pipe was the same as on the outside of a ship; in fact, he had arrived at an exactly contrary conclusion. His attention was first called to the subject, when making some calculations to check the data given in Mr. Leslie's Paper, "On the Flow of Water through Pipes."[1]

In that Paper Mr. Leslie computed the actual gradients of the pipes, in several large examples, by dividing the length by the total height of head. The gradients thus obtained gave an easy mode of calculating the friction of the water in the pipes. It was only necessary to divide the total weight of water in the pipes, by its amount of gravity down the plane, which constituted the total moving power; and then to divide this quantity by the whole internal superficial area of the pipes, when the friction, or resistance per superficial foot, would be obtained. In this manner Mr. Phipps found that, at a velocity of 12·2 miles per hour, equal to 17·9 feet per second, the friction amounted to 2 lbs. upon each square foot, whilst according to the admirably-conducted experiments of Beaufoy,[2] the friction on the side of a ship at the same speed, was only 1 lb. on the square foot. As a further proof of the probable correctness of his deduction, he mentioned that, if the friction per square foot on the side of a ship was equal to that in a pipe, the power lost by friction in the case of the 'Rattler,' previously alluded to, would be equal to 340 H.P. out of a total power of 428 indicated H.P., leaving only 88 H.P. for overcoming all the other resistances.

Mr. HAWKSLEY said he was well aware of Mr. Leslie's experiments, which were all made on small pipes, but he did not draw the same inference from them. He had calculated the resistance in a pipe of 12 inches diameter, and in a pipe of 100 inches diameter, and found they both gave, as might have been expected, the same measure of resistance. At a velocity of 15 feet per second, the resistance was 25 ounces to the square foot. If the radius of a pipe was made indefinitely large, the side became, for any short arc practically straight, and it was therefore manifest that it was immaterial, as regarded the measure of the resistance, whether the water was outside, as in a ship, or inside, as in a pipe. He intended to institute a set of experiments, for the express purpose of clearing up the existing difficulties, with respect to the resistance of fluids acting by impact, on plane and curved surfaces,

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xiv., p. 302.

[2] *Vide* "Nautical and Hydraulic Experiments, with numerous Scientific Miscellanies." By Col. M. Beaufoy. 3 vols. 4to. London, 1834.

which, when completed, he would place before the Institution. These might lead to some modification of his present views, but he thought not to any important extent.

Mr. BRAMWELL wished to call attention to a remark which had been made, that a great portion of the apparent economy of working marine engines expansively resulted from the reduced power which was exerted. That position would be generally agreed to, but the subsequent statement, which induced the opinion that working steam expansively was a costly process, must be carefully examined, before it could be admitted, and was suffered to go forth to the world, uncontradicted, and to a certain extent sanctioned by the Institution. The fact stated was, that in the trials of the 'Retribution,' whilst the amount of steam used, when working expansively, was only 6½ cubic feet, and 11 cubic feet, when using full power, yet the consumption of coals was 8 lbs. per indicated H.P. per hour in the former case, and 5 lbs. per hour in the latter. Thus with about 60 per cent. less steam, the coals consumed amounted to 60 per cent. more.

With regard to the friction of vessels passing through water, a curious experiment had been tried upon a boat between New York and Perth Amboy, by blowing air along a flat bottom externally, and preventing it from escaping laterally by slight keels, or ribs. He had seen the boat at work, and had been told, that when the pumps were thrown out of gear, the boat lost speed. It was said, however, that had the power employed to work the air-pumps been applied to the paddle wheels, a better result would have been obtained.

Mr. HUMPHRYS said, the conditions in a marine engine were not the same as in land engines, whether stationary, or locomotive. A record of the performances, for three or four years, of H.M. paddle-wheel steamer 'Fury,' of 515 H.P., showed that, if the coal burnt and the distance run were alone considered, a favourable conclusion would be arrived at, as to working expansively; but the question now was, the quantity of fuel consumed per horse-power, not the distance run with a given quantity of coal. It had not occurred to the engineer in that case, to see what the power cost. As, however, he had given the mean pressure upon the pistons and the number of revolutions per minute, Mr. Humphrys had been enabled to calculate the consumption of coal per horse-power per hour, and this he had added to the following Table, giving the results of the performances alluded to:—

	Coal consumed.		Distance run per Day.	Distance the Coals would last.
	Per Day.	Per H.P. per Hour.		
	Tons.	Lbs.	Statute Miles.	Statute Miles.
Full power . . .	50	3·97	264	2,112
1st grade of expansion	40	4·24	240	2,400
2nd ditto	36	4·79	222	2,466
3rd ditto	33	5·46	211	2,555
4th ditto	28	5·57	190	2,698
5th ditto	22	5·8	155	2,790
6th ditto	19	7·53	130	2,730
7th ditto	15	8·87	110	2,926

In a pamphlet by Capt. W. Ramsay, R.N., there were given the performances of H.M.S. 'Terrible' in her early days. She was a very fine vessel, and had a pair of engines of unquestionable efficiency. The following results (except the coal consumed per H.P. per hour) were recorded in a tabular form:—

	Indicated H.P.	Coal consumed.		Speed.
		Per Day.	Per H.P. per Hour.	
		Tons.	Lbs.	Knots.
Full power . . .	1,850	100·5	5·07	12·8
1st grade of expansion	1,640	76·0	4·33	
2nd ditto	1,400	68·0	4·53	
3rd ditto	1,200	58·0	4·51	
4th ditto	1,000	51·0	4·76	
5th ditto	800	47·1	5·54	
6th ditto	650	44·75	6·42	9·8

These statements accorded with his own observations in a great number of cases. In fact, he had never found an instance in a steam-boat, where the cost of the power was less, when working expansively, than it was when working full power. The moment a marine engine began to work expansively, beyond what was due to the set and lap of the slide, the speed of the piston was reduced, and an important element in obtaining economy in working steam expansively was lost.

The 'Terrible' was a case of large engines working moderately. He would now give a case of comparatively small engines working hard. The 'Llewellin,' of 350 nominal H.P., when exerting her full power of 1,800 indicated H.P., consumed $3\frac{3}{4}$ tons per hour, or 4·6 lbs. per H.P. per hour, being a marked difference in favour of the small engines worked up to full power. Again, the 'Rosamond,' of 280 nominal H.P., when exerting her greatest effort of 492 indicated H.P., consumed $4\frac{3}{4}$ lbs. of coal per indicated H.P. per hour; but when working only to 168 indicated H.P., she consumed 7·9 lbs. of coal per H.P. per hour.

In marine engines, the attempts hitherto made for realising the benefits to be derived from working expansively had not been attended with adequate success. He believed that the loss, when working at a high degree of expansion, arose to a great extent from the condensation over the extended surfaces to which the steam was exposed, as only indifferent means were adopted for keeping up the temperature, and thus there must necessarily be a loss of mechanical effect. In the case of the 'Retribution,' before alluded to, there was a cylinder 72 inches in diameter, with a length of stroke of 7 feet, making when the indicator card, Fig. 1, (p. 339) was taken, eight to nine strokes per minute. Looking at the speed of the piston, and the vast amount of material to which the steam was exposed, without any means for keeping up its temperature, he was not surprised that three-fourths of the steam was condensed, without producing the effect on the machinery. In a large stationary pumping engine there was a mere breath of steam at the top of the stroke, and during the time this steam was giving out its power, the piston was travelling at an immense velocity; whereas, in a marine engine, there was a much slower action of the piston. In the land engine every means was taken to keep up the temperature of the steam, throughout its entire course, and if that was not done, much of the mechanical effect was lost.

The area of fire-grate might be received as an approximate index of the coal expended. In the 'Asia,' one of Cunard's line, the fire-grate to supply steam for one indicated H.P., when the engines were worked at 14¼ revolutions per minute, exerting 1,850 H.P., was ·234 of a square foot; whilst in the 'Garland' Dover Mail Packet, working to five times her nominal power, the fire-grate surface was ·198 of a square foot per horse-power.

It had been stated by a high authority, that "an engine worked under its force yields much more power, in proportion to the coal expended, than when worked to its full power." Now, Mr. Humphrys contended, on the contrary, that a marine engine, as now generally made, and as they were made at the time that statement was advanced, gave out the greatest amount of power, per coal expended, when exerting its utmost effort. His impression was, that the loss from working expansively in marine engines, arose from not observing the conditions necessary to realize the benefits of expansion. He was prepared to admit the value of it. But there would always be a difficulty in marine engines, because the load was uniform, whilst in land engines the load was accommodated to the power developed, and the full speed of the piston was thereby always maintained.

Mr. ANDREW HENDERSON differed entirely from the views of the Author of the Paper, which he understood to be, that the area

of the midship, or the largest transverse, section was the only element of resistance, and that the form of the vessel had little or nothing to do with the question of speed. He considered, on the contrary, that form and displacement were the principal elements, though there were others which he had endeavoured to eliminate. The weight of cargo a ship would carry would be represented by the displacement, but not by the midship section.

He had collected, for a number of years past, the particulars of the performances of different vessels, and the archives of the Institution now contained, in a tabular form, the records of the dimensions, proportions, tonnage, draft, displacement, area of midship section, weight, and other elements of resistance, of about one hundred vessels, together with the dimensions of the engines, the nominal horse-power, and the speed realized. He hoped that, by the co-operation of the Members, these records would be still greatly augmented. Ten years ago, he had brought the subject of 'Ocean Steam Navigation' before the Institution;[1] and again, in 1853, he had presented a Paper 'On the Speed and other Properties of Ocean Steamers, and on the Measurement of Ships for Tonnage.'[2] The question had also been discussed at the Society of Arts, and latterly at a meeting of the British Association at Dublin, where Mr. J. R. Napier contended, as did the Author of the present Paper, that the area of the midship section was the principal element of resistance, and proposed to use the formula $\frac{V^2 \text{ mid-sect.}}{\text{Ind. H.P.}}$, for ascertaining the comparative merits of vessels, by their coefficients, or index numbers, in place of the formula $\frac{V^3 D^{\frac{2}{3}}}{\text{Ind. H.P.}}$ used in the trials of H.M.S. 'Rattler.'

The difficulty of obtaining sufficiently detailed information, as to the performances of vessels at sea, was so great as to prevent any correct general law being at present established. The most complete series of details of this nature which he had yet obtained, was of the performances of the steam ships of the Peninsular and Oriental Company, for six years, while performing mail service, over a distance of 1,500,000 miles. The result showed at least 10 to 15 per cent. less speed than had been expected of them.

The Admiralty had been applied to for a return of the dimensions, displacement, draft, and indicated horse power of certain of the vessels in the Royal Navy, but the reply which had been given was, that the information had better be obtained from the mercantile marine. He had just received a tabulated statement of the results of the trial trips at the measured mile of thirty of the

[1] *Vide* Minutes of Proceedings Inst. C. E. for 1847, vol. vi., pp. 484 to 495.
[2] *Vide* Minutes of Proceedings Inst. C. E. for 1853-4, vol. xiii., pp. 1 to 63.

newest vessels belonging to the Peninsular and Oriental fleet, comprising the displacement, area of midship section, indicated horse power, and speed realized, and these he had embodied in a Table. In this table he had also given the index numbers, or coefficients of displacement and area of nine of these ships, calculated by both the formulæ given above; but the elements of the calculation being the results of test trials in smooth water, would vary when in a sea way, or on a long voyage, where the quantities were constantly changing.

The anomalies of the present system of tonnage measurement and registration were likewise exemplified in the Table, which was only submitted as an approximation to the desideratum of a uniform system of recording facts, of the performances of steam vessels at sea, under all circumstances.

A closer test of the relative qualities of vessels could be obtained by recording on the log, the indicated horse power from diagrams taken daily during the voyage, and at the same time the displacement, area of midship section, and mean draft of water. The mean of these coefficients, taken daily, at the end of the voyage, would afford a fair average of the qualities at sea; in the same way that the general average speed of the contract steamers was calculated from the Post-office returns, as shown in the Table, from which it appeared that the 'Haddington' averaged a speed of 8·154 miles per hour over 114,240 miles run, and the 'Hindostan' a speed of 9·195 miles per hour over 33,320 miles run. The mean draft, displacement, and area of midship section could be ascertained at the exact time of taking the indicated horse power and speed, by a pipe, or water gauge, through the keel about the middle of the length; a scale of displacement, and area of midship section furnished by the builder, or surveyor, being attached to the pipe.

Mr. R. ARMSTRONG said, the immediate object of the Paper under discussion was, "An examination of the circumstances that appeared to limit the maintenance of higher speeds in deep-sea navigation." He implied from the proposition of that subject by the Institution, that the necessary requirements were not generally understood.

For the advancement of naval architecture, and the progress of steam transport economy, it was necessary to have the power of discriminating between good and bad vessels, of telling whether the engine was doing its assigned duty, and whether the vessel was fulfilling the requirements for which it was designed, and of reducing the necessary requirements, for any velocity, to a simple mathematical calculation. As a proof that the necessary requirements were not understood, the 'Parana,' 'Magdalena,' and 'Orinoco,' belonging to the Royal West India Mail Company,

were adduced. When increased velocity was obtained by that Company, it was only by an immense increase of power. And in all cases where greater velocity had been obtained by the same nominal H.P., it had been due to the superior effectiveness of the engines.

He asserted, that the power of elimination was concentrated in the proposed formula

$$V^2 = \frac{\frac{2}{3}\text{ I.H.P.} \times 100}{\text{Mid. Sec.}}$$

But whether the formula was theoretically correct, or not, it might be conceded as a standard of comparison, for recording the progress of naval architecture, on the same principle that the power of a steam-engine was calculated. Without using comparisons, by means of that formula the well-known list of screw vessels in H.M. Navy had been tabulated. This showed, that as the vessels with the highest velocities were all on the positive side of the speed deduced by the formula, it might be safely calculated, that the expenditure of power above the square would not negative the speed deduced, up to 18 miles per hour; this fact was adduced in proof that "the power only increased as the square of the velocity."

In proof of the assertion that the form was not necessary in calculations of velocity, Mr. Armstrong pointed out that the speeds of the 'Vulcan,' 'Minx' (diminished), 'Encounter,' 'Sharpshooter,' 'Himalaya,' and 'Ajax,' were deduced by the formula to within one-fifth of a mile; and the speeds of the 'Archer,' 'Arrogant,' 'Rattler,' 'Rifleman,' 'Niger' (diminished), 'Alma,' 'Candia,' 'Ava,' 'Aden,' 'Dauntless,' 'Phœnix,' 'Conflict,' and 'Amphion,' were deduced within one mile. These variations were believed to be entirely owing to the various degrees of efficiency of the propellers, as might be seen by the following Table:—

——	Ratio of Speeds.	Pitch to Diameter.	Revolutions.
Plumper	1·21	·62	100
Reynard	1·21	·91	108
Archer	1·13	·86	108
Arrogant . . .	1·12	·96	55
Rattler	1·12	1·10	104
Rifleman . . .	1·08	1·12	110
Niger	1·06	1·36	68
Alma	1·06	1·32	57

This Table was in exact accordance with experiments upon the 'Ajax,' 'Dauntless,' 'Minx,' 'Phœnix,' 'Plumper,' 'Rifleman,'

(diminished), and 'Sharpshooter'; and therefore proved, that the form of the vessel was not the cause of the variation from the speed deduced by the formula.

The element "frictional resistance" was completely ignored by the power required, to attain nearly the same velocity, in the 'Himalaya' being 400 indicated H.P. less than the proportionate power to the midship section of the 'Fairy;' although the 'Himalaya' was three times as long, twice as broad, and had three times the draft of water, whilst the immersed surface was as 20 to 1; and by the fact, that the longest and largest vessels were all on the positive side of the speed deduced by the formula, and the smallest on the negative side.

In the cube theory, the combination of space with velocity was unphilosophical, and against the opinion of writers on Dynamics and Hydrodynamics. In the well-known tabulated list of screw steamers of her Majesty's Navy, the 'Minx' was the only example that favoured this theory. In a comparison of the 'Minx' (diminished), 'Teazer,' and 'Fairy,' the facts were in favour of the square theory; and from experiments on the same vessels, the 'Dauntless,' 'Desperate,' 'Termagant,' and 'Charlemagne,' the deduced power by the square theory was under the actual power in every case. In a comparison of the 'Himalaya,' 'Amphion,' 'Minx,' and 'Termagant,' the facts were decidedly in favour of the power increasing as the square of the velocity.

He attributed the increase of speed, by lengthening the bows of steam vessels, to the effect of that increased length decreasing the normal immersion of the after end of the vessel at high velocities, and not from any decreased resistance on the bow of the vessel. In corroboration of this, he stated, that the trials of the 'Flying Fish' showed no increase of velocity by the lengthening of her bows, at half, or three-quarter power, though with full power the speed was increased from 11½ knots to 12½ knots. As a further illustration, a vessel was assumed of the same displacement as the 'Himalaya,' but with rounder water-lines, drawing 18 inches less water, and having 70 square feet less midship section. He would then ask, whether the advantages of the sharp water-lines of the 'Himalaya' were equivalent to the rounder water-line of the assumed vessel, which had 160,000 tons less water to displace, in sailing one hour. The formula, when applied to the four experiments with the 'Desperate,' alluded to in the early part of the discussion, enabled the most effective and economical power to be ascertained. In the first experiment, with four boilers and four cylinders, the effective H.P. was 68 per cent. under the indicated H.P.; in the second, with three boilers and four cylinders, the effective H.P. was 45 per cent. under the indicated H.P.; in the third, with two boilers and four cylinders, the effective H.P. was

only 17 per cent. under the indicated H.P.; and in the last, with one boiler and two cylinders, the indicated H.P. was 18 per cent. under the effective H.P. The inference he deduced from these facts was, that small boilers and large engines would be the most economical and effective, and they induced doubts as to the accuracy of the rule for calculating indicated H.P., which was further confirmed by the recorded results of the performances of the 'Retribution' and of the Dover Mail Packet 'Garland.' It had been said, that 169 indicated H.P. had propelled 440 square feet of midship section in the 'Desperate' at the rate of 7 miles per hour. This he believed to be impossible, for in the

	I.H.P.		Mid. Sec.			
Plumper ..	148	propelled	204	at the rate of	8·47	miles per hour.
Reynard ..	165	„	184	„	9.43	„
Archer ...	345	„	372	„	8·93	„
Ajax	846	„	807	„	8·16	„
Phœnix ...	382	„	347	„	8·11	„
Amphion .	592	„	546	„	7·71	„

In conclusion, Mr. Armstrong expressed the hope, that, whether the theory he advanced was true, or not, the discussion to which his Paper had given rise would tend to advance the science of naval architecture, and to bring Steam Transport Economy within the range of arithmetical calculation.

Mr. G. P. BIDDER, V.P., observed, that the Paper had been, and with justice, severely criticised, for promulgating doctrines so decidedly at variance with the actual state of scientific knowledge; and as in the reply to the observations of the various speakers, the Author did not appear to perceive the errors into which he had fallen, the employment of other arguments with a gentleman who contended, that the power was not as the cube, whilst he admitted that the resistance was as the square, would be as useless as to attempt to hold a conversation with him in a language which he did not understand. Still the discussion would be useful in having elicited many facts which, if properly treated, would assist in throwing light upon the practical treatment of the question of the resistance to bodies passing through fluids.

Even Bossut and other eminent experimenters had neglected essential elements of resistance, and thus had permitted the existence of anomalies which had obscured the subject. For instance, whilst the effect of the angle of the bow had been carefully investigated, that of the angle of the stern, which was almost of as great importance, had been entirely neglected. The question of that important element, friction, also had not been duly considered, and although, when mentioned, it had been argued, that the friction of fluids in the interior periphery of a pipe differed from that of the exterior surface, such a proposition could

not be admitted. It was incumbent on the Institution to prosecute this inquiry, to bring the subject within the province of scientific demonstration, and to reconcile the apparent anomalies with which it at present abounded.

The question also of the asserted increase of expenditure of fuel when working steam expansively in marine engines, must be thoroughly investigated, as though the effect of condensation might be considerable, in large engines working slowly, it was not sufficient to account for the augmentation of fuel expended in producing a less effect. If this explanation was correct, it showed that there was room for mechanical ingenuity to overcome the condensation, for in locomotive and in pumping engines there was undoubtedly economy, by working steam expansively.

With regard to the best form of vessel, that point could not be settled, without a series of experiments to determine each element of resistance separately, showing what was due to friction, what to the shape of the bow, and what to the shape of the stern. Mr. James Walker, (M. Inst. C. E.,) had many years ago made experiments on this subject, and had presented a Paper to the Royal Society, "On the Resistance of Fluids to Bodies passing through them."[1] These experiments were made with boats 20 feet and 28 feet in length, in the East India Docks, and by such application of power as could be correctly estimated and collated with the speed attained. All the results confirmed the accepted rule of the resistance being as the square, and the power as the cube of the velocity. This first series of experiments was not, however, so valuable as the second series, in which the angles of the vessels were altered definitely, and an account of which, it was hoped, would be given to the Institution.

There were many Members, from whom on all these questions, valuable Papers might be obtained. He hoped they would devote some of their time and knowledge for the benefit of the profession, and from the partial promises already received, there was reason to expect that such Papers would shortly be laid before the Institution.

March 17, 1857.

ROBERT STEPHENSON, M.P., President,
in the Chair.

The discussion upon the Paper, No. 961, "On High Speed Steam Navigation, &c.," by Mr. R. Armstrong, having been renewed, was continued to such a length as to preclude the reading of any other communication.

[1] *Vide* Phil. Trans. for 1828, pp. 15 to 22.

March 24, 1857.

JOSEPH LOCKE, M.P., Vice-President,
in the Chair.

The discussion upon the Paper, No. 961, "On High Speed Steam Navigation, &c.," by Mr. R. Armstrong, having been renewed, was continued to such a length as to preclude the reading of any other communication.

March 31, 1857.

GEORGE P. BIDDER, Vice-President,
in the Chair.

The discussion upon the Paper, No. 961, "On High Speed Steam Navigation, &c." by Mr. R. Armstrong, having been renewed, was continued to such a length as to preclude the reading of any other communication.

April 7, 1857.

GEORGE P. BIDDER, Vice-President,
in the Chair.

THE following Candidates were balloted for and duly elected:—JAMES GRAHAM, JOSEPH HARRISON, SAMPSON LLOYD, BRYCE MCMASTER, JOSEPH PITTS, and CHARLES RIGBY, as Associates.

No. 964.—"On the laying of the Permanent Way of the Bordeaux and Bayonne Railway, through the Grandes Landes."[1]
By FRANCIS ROUBILIAC CONDER, Assoc. Inst. C.E.

IT having been suggested, that some account of the permanent way laid over the Landes, or barren country of the south-west of France, and of the peculiar difficulties which had to be surmounted by the English Contractors in its construction, would offer some points of interest, the following brief description has been drawn up.

On the 2nd of February, 1855, Messrs. Conder, Goode, and Co. signed a contract with the Compagnie du Midi, for the laying of the permanent way from Bordeaux to Bayonne. The line, starting from the western suburb of the city of Bordeaux, had for some considerable time been in operation, as far as the little fishing village of La Teste, which is situated at the head of the wide estuary of the Leyre. The range of sand-hills which shelters this piece of water, from the frequent storms that sweep the Bay of Biscay, give it the repose and the aspect of an inland lake. Two miles west of La Teste, the village of Arcachon stretches along the southern shore of the estuary, embosomed in the forests of pines, which, planted by the first Napoleon on the desert sands of the Landes, now fringe the seaboard for a hundred miles, and afford an unfailing supply of indifferent timber, and an annual yield of resin. Arcachon is the bathing-place of Bordeaux, and is an agreeable retreat from what are called the "great heats" of the Landes, and the wine-growing district, although the danger of the bar has checked its development as a seaport town.

The surface of the country lying between the embouchure of the Leyre and that of the Adour, which constitutes the department of the Landes, consists of a fine dry sand, and the part that is not protected with pine is chiefly covered with heath, furze, and rushes. A few miserable hamlets are scattered here and there, but the in-

[1] The discussion upon this Paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

tense heat of the sun, the arid character of the soil, and the entire absence of any roads, or of materials for their construction, have checked both population and agriculture. In the winter the Landes are wet and swampy, and agues and marsh-fevers are prevalent. The inhabitants are generally feeble and unhealthy, and a traveller may ride for many miles over this inhospitable region without seeing any human being except a few shepherds, striding over the wide solitudes on long stilts. The facility with which they thus move is remarkable, and they are able to pick up a stick, or even a piece of money, from the ground, without dismounting. Leaving the La Teste line at about 30 kilometres from Bordeaux, the Bayonne line strikes directly across the heart of this desert to the neighbourhood of Dax, from which town to Bayonne it runs through an agreeable and populous country.

The works of construction over this district were naturally few and light. But great difficulties had been encountered by the Company in their execution, and it is stated, that the hardships to the workmen, arising from the imperfect supply of food and lodging, were so formidable, as to compel the interference of the Prefect of the Department.

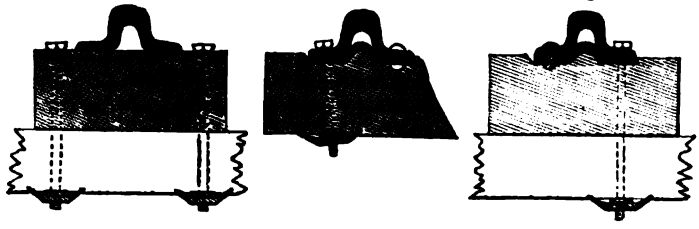
In the case, however, of laying the permanent way, the Contractors had a right to calculate on a rapid and certain communication with Bordeaux, for the northern portion of the line; and for the other stations, they considered that if the Compagnie du Midi could arrange the supply of such weights as are required for permanent way, the transport of rations of food would be a less serious difficulty. It was accordingly provided in the contract, that a sufficient supply of materials for a fortnight's work should always be kept on hand by the Company, at each station where laying was to take place, and that waggons for housing the workmen should also be furnished, in fixed numbers, by the Company. The free use of the Company's trains was also secured to the Contractors.

The specification for the work was taken in great part from the English specifications for laying the broad-gauge system of railway, one of which, indeed, is referred to in Article 30 of the "Cahier des Charges," as explanatory of the general conditions. But although this was the case, and although the system adopted was termed by the Engineers of the Company "Voie Brunel," it will be seen, that the structure, even if all the materials had been perfect, was of a very inferior character. To the suggestions which the Engineers kindly invited, and which the Contractors thought it due to their character to make on these points, there was, unfortunately, the sufficient reply, that it was too late, for that the contracts for the supply of the materials were all in the course of execution.

The longitudinal timbers were specified to be of the wood of the

Landes Pine (*Pinus Maritimus*), delivered by the Company straight, and sawn square at the extremities. Their lengths were to vary by intervals of 50 centimetres, from 4 metres to 7½ metres; but of these one-tenth part might be of the length of 2 metres 80 centimetres. The transverse section was specified at 18 centimetres for the upper face, 30 centimetres for the under face, and 13 centimetres for the depth, as minimum dimensions, thus giving a sectional area of 312 square centimetres, or not quite 50 English inches. The Great Western specifications, with a minimum cross section of from 84 square inches to 98 square inches, insist on a mean length of 30 feet, and a minimum length of 22 feet, for each longitudinal timber. Thus both the average length and the cross section of the longitudinal timbers were to be little more than half of those specified for the English lines. The transoms were specified to be 2 metres 40 centimetres long, with a section of 25 centimetres to 31 centimetres in width, by 10 centimetres in depth. The rails were to be 6 metres in length, weighing 30 kilogrammes per metre; they were to be laid end to end, and riveted to joint-plates 40 centimetres in length.

Fig. 1. Fig. 2. Fig. 3.



It will be evident, that the sole chance of stability, of a way composed of such numerous short lengths of light timber, must depend on the substantial and workmanlike manner in which it was framed together. In the Great Western lines this object is effected by the housing of the transoms into the longitudinal timbers, and by tie-bolts, which pass through the latter, and are firmly secured to the former; and the continuity of the longitudinal timbers is secured by a sort of dowell, called a "joint-plate," which has been found, in practice, to unite the ends of the timber with a degree of solidity that could hardly have been expected, but which is an essential condition in this system. On the Midi line, unfortunately, all these precautions, which a long experience in this country had proved to be necessary, were omitted. The short longitudinal timbers were merely laid end to end on the transoms, the rails were laid on and riveted to the joint-plates, and the sole tie between the outer and the inner rails was effected by the bolts, which passed vertically through the rail, the longitudinal timber, and the transom. The

result of this plan was, that the riveting of the rails, an operation which had been tried and abandoned in this country, and which is attended by many serious evils, was almost the only operation on which the gauge of the way depended. The timbers could not be framed together until the rails were riveted, as the irregularities in their length, and the great amount of expansion and contraction due to the climate, rendered useless any attempt at fitting without riveting. The twisting and warping of the timber threw an undue strain upon the rails, which were not designed to bear such lateral stress, and the tendency of the working of the traffic to throw the line out of gauge, being only resisted either by the lateral stiffness of the rails, or by the tension of the holding-down bolts, which was exerted not in the line of, but at right angles to, the disturbing force, became evident on the first passage of a heavy engine, at a moderate speed.

It is not the object of the present Paper, to offer any opinion on the several descriptions of permanent way, that are used in this country. But it is not inconsistent with this reserve to remark, that in a desert country, like the Landes, a primary requisite ought to be, to select such an arrangement as would leave the minimum of work to be performed on the ground. The quality of the timber supplied by the country, the difficulty of carriage, and the absence of any accommodation for the workmen, were so many reasons for adopting, in the present instance, a sleeper road of the simplest construction; so that the chairs might have been attached to the sleepers before they were sent on the line, and a series of gangs might have been so disposed, to follow one another in regular order, placing the sleepers on the line, laying the rails, keying up, packing and straightening. The rapidity ultimately attained might have been at least double, if such had been the nature of the way. In this case, the delivery of the materials on the ground, was the measure of the whole operation. Roads there were none, and the Company, which had at first undertaken to deliver all the materials of the way, so that the Contractor should not have to provide for a mean lead of more than 4 kilometres, and that over their own line, were obliged to have recourse to the latter for the delivery of 110 kilometres of way, starting from Bordeaux. Timber was delivered at four intermediate stations.

The usual course of the operation was, that the rails, which were sent in trucks as far as the way would allow of their delivery, were trailed forward by horses, and laid as a temporary way. Over this temporary way the transoms, longitudinal timbers, and other fittings were conveyed, and disposed along the line. A set of carpenters followed, to arrange the timber work, which, however, could only be bolted together temporarily, until the rails were laid. The rails were then laid on the timber, either by removal from the

temporary road alongside, or from fresh deliveries made from trucks running on this road, as the case might be. The rail lifters were followed by gangs of riveters, with their forges, placed about 20 chains apart. After riveting, the rails had to be blocked up from the timbers, to allow of the adzing out of the seat of the joint-plates, an operation which could only be performed under these unfavourable circumstances, in consequence of the extreme irregularity in length of the rails, as well as of the longitudinal timbers, and of the great amount of expansion and contraction which took place throughout the day. The rails being relaid on the timber, a gang of borers succeeded, and it was in this part of the work that the pluck and sinew of the English workmen were indispensable. All the rest could be, and was, well executed by Frenchmen, before the close of the undertaking, but all efforts to organize a French gang of borers failed. The borers were followed by a set of men who placed the bolts, and these by another set who screwed them up, and these again in their turn by packers and by straighteners.

It was impossible to confine such a series of operations to a less extent of line than 2,000 metres, and frequently the head of the work was three miles in advance of the finished work. It was of extreme importance, that the gangs should follow one another as closely as possible, as the supply of the next day's materials, which had to be conveyed over the road, as far ahead as possible, was stopped by any interruption. The obstacle caused by the riveting was of the most serious description, not only from the irregularities in the lengths of the rails, which frequently required drilling, and from the subsequent delay in adzing the seats, but from the fact, that no compensation could be allowed for expansion and contraction. An unexpected variation in the temperature, or a shower of rain, often deranged the whole riveted and unbolted portion of the way, and delayed the works for many hours at a time. A kilometre of riveted rail has been known to become suddenly elongated, so as to form a series of vertical and lateral curves, which was quite impracticable until nightfall lowered the temperature and reduced the additional length.

It will already have been remarked, that mechanical difficulties of no ordinary kind were enhanced in a tenfold degree by the difficulties of communication, and the desert nature of the scene of the operations. The letter-carrier of the district availed himself of the sanded surface of the railway for his daily journey, which was performed upon stilts. Wild ponies, accustomed to the Landes, and the trains that conveyed the materials, were the only mode of communicating from point to point. Lodgings there were none; and as, for days together, the head of the work was advanced a mile and a half in twenty-four hours, it was not pos-

sible to make use of the material-train to convey the men to their quarters. The natural jealousies, not only of race, but of province, not only between English and French workmen, but between the latter from the north and those from the south, the necessity of giving orders in both tongues, or even in the "patois" which the workmen used among themselves, the burning heat of the sun, the necessity of commissariat arrangements, on so extensive a scale as to provide for sending even potable water from Bordeaux, combined to give a military character to the enterprise, such as rarely attends the labour of the Civil Engineer.

The Imperial Government kindly supplied military tents, which covered a portion of the workmen. Others were housed in a temporary village, built on railway-trucks, and moved from one to two miles ahead along the railway per diem. A yet larger number, towards the close of the work, had to bivouac around pine fires, which ill protected them from the cutting winds that swept from the Bay of Biscay by night, in strong contrast to the tropical heat of the noonday sun.

The main cause of the unprecedented exertions made by the Contractors remains to be told. The contract was finally arranged on the 20th of March. The Company was not in a position to call for the employment of seventeen gangs, the maximum force stipulated, until the 4th of June. But on the 27th of May, the Engineer informed Mr. Conder, that His Majesty had expressed a desire, that the entire line to Bordeaux should be opened by the 15th of August, and that the Chairman of the Company had promised that this should be done.

Although no parties to an undertaking, which so materially and so unexpectedly varied their position, the Contractors felt unwilling to throw upon the Engineer of the Company, the responsibility that must have attended a refusal, on their part, to devote their utmost energies to redeem the pledge of the President. They, therefore, made arrangements for commencing the work at four points, at which the materials were to be delivered by the Company, and they engaged Engineers and numerous workmen, both in this country and in France, to arrive at the several points at the times fixed for the deliveries of the materials. By the 8th of July, however, only one cargo of rails had been delivered at any point except Bordeaux; and the men intended for the other stations had thus to be placed on the works proceeding from that end of the line, a circumstance which tended greatly to disorganize the arrangements, both of the work itself and of the commissariat. To meet, as far as possible, these disappointments on the part of the Company, and to prevent the great sacrifices already made from being altogether unavailing, a fourth arrangement was entered into, at Paris, on the 20th of July, under the

advice of the Vice-chairman of the Company. By this agreement the Contractors undertook to lay, from the Bordeaux end of the line, at which they were then at work, a length of 28 kilometres, by the 31st of August. Concentrating their energies on this point, they left to the Engineer of the Company to superintend, as day work, the other portions of the line, to which access was possible, both by road and river, and where the delivery of materials was more under the control of the Company. The Contractors further supplied from England, 2,000 tons of "Barlow's Saddle-back Rail," in order to expedite, as much as possible, the exertions of the Company. This enabled the latter to complete a portion of about 30 kilometres, from Dax towards Bordeaux, within a few days after the termination of the Contractors' own portion, through the Landes. All idea of opening from Dax to Bayonne was then abandoned for more than six months.

The arrangements for this purpose were not completed, so as to allow of a regular daily progress, until the 1st of August, by which time a fresh intimation was received from the Engineer-in-chief, to the effect, that His Imperial Majesty had expressed a desire to return from Dax to Bordeaux by railway by the 26th instant. A strict adherence to the tenor of the agreement of the 20th of July would have rendered it impossible for His Majesty's wish to be fulfilled. The whole of the past exertion and loss, therefore, appeared to demand an extraordinary effort, and how far this was made by the Contractors the dates and distances will testify.

On the 5th of August the state of the works was such, that a progress of 1·07 kilometre per diem was requisite to carry out the engagements of the Contractors with the Company. Instead of only reaching Morcens by the 31st of August, the Contractors had advanced 7 kilometres beyond it by the 25th. Had the reduced, and far easier, length left to the management of the officers of the Company been advanced at about half this speed, His Imperial Majesty might have returned to Paris along the line, at the hour previously intimated.

Between the 5th and the 20th of August, one entire day was lost from the non-supply of rails by the Company, another from the occurrence of the Emperor's fête on the 15th, and two more by heavy rain. The actual number of working days, including Sundays, was thus reduced to seventeen, in which, in the hottest season of the year, and under the circumstances above described, a mean speed of 2·06 kilometres per diem was attained, and a length of 35 kilometres was laid, with rails sent over the line in course of construction.

In presenting this brief narrative of exertions which are believed to be unprecedented, it will be some recompense, that the

facts should be placed on record, among the archives of engineering struggles.

The opening of the railway through the Landes has an interest which far exceeds that of any personal narrative of difficulties overcome, or of success achieved. It may have an influence exceeding even the limits of Imperial France, and affecting the climatological aspect of Southern Europe.

The great deterioration of climate in Spain, in Southern France, in Northern Italy, and above all in Palestine, which has occurred since historic times, is traced, by thoughtful naturalists, to the destruction of the trees that formerly clothed and sheltered the now barren hills. The experience of thirty years in the New World confirms that of thirty centuries in the Old, as regards the sensible change, both in thermometric and in hygrometric conditions, produced by the clearing of forests. The sirocco, the bise, and the mistral, now scorch in turn the shores of the Mediterranean, and the difference between the exhilarating and tonic air of the Campanian plain, and the pestilential exhalations of the Pontine marshes, is due rather to human industry and careful culture, than to geographical, or geological causes.

The growth of the pine forest, skirting the Grandes Landes, has produced a marked climatic effect, of a local and limited nature. The two miles separating Arcachon from La Teste divide climates, more different than those severed, under similar conditions of culture, by half the latitude of France. The successful effort to redeem from the ague and the Landes fever, so wide a district as the desert now traversed by the Bordeaux and Bayonne Railway, would have a beneficial influence probably throughout the entire south of France, and an economic value equal to the reclamation of a province from the sea. This effort is rendered possible by the railway. Stone and water, the two great deficiencies of the district, may be obtained, at least on a considerable part of it, at no great depth below the surface of the soil. From stations now merely nominal, such as that of Sanguinet, which in 1854 was marked by a single tree, practicable roads can be made, by means of the ferruginous conglomerate underlying the fine black sand of the district. The way thus opened for the communication of labour, it will be easy to drain the swamps, to form artificial lakes against the summer droughts, to pierce the soil for the underlying supply of water, to plant the common pine, or the cork oak, to intersperse belts of plantation, with fields of maize, or of buckwheat, and to allow wholesome grass to replace, on the drained and irrigated soil, the heath and the rush. France will then owe not only the chaining of her rivers, and the rebuilding of her capital, but also the bloodless

conquest of a great province to the third Napoleon; and the French child, in 1954, may treat as a clumsy fable, the story of the difficulties that attended the laying of the Bordeaux and Bayonne Railway through the Grandes Landes.

The Paper is illustrated by a series of diagrams, from which the woodcuts, Figs. 1, 2, and 3, are compiled; and is accompanied by a copy of the specification, or "Cahier des Charges," for its construction.

[Mr. HAWKSHAW.

Mr. HAWKSHAW, V.P., remarked, that in a country like the Grandes Landes, where timber was scarce, the longitudinal system of permanent way should not have been adopted, for one essential of its success was the use of long pieces of timber. The shorter pieces of timber, there used, would have served as cross sleepers, with a less consumption of material, and such a road could have been laid with greater rapidity than that described in the Paper. The longitudinal timber road had been adopted, in many instances, in this country, and he believed almost every variety of that system had been tried. He had himself applied it in twenty different forms. On the Manchester and Bolton line, more than twenty years ago, the ordinary contractors' rail was fastened to longitudinal timbers, which were let into cross timber transoms. The next variety he adopted was the use of a plank underneath the joints of the longitudinal timbers, and a bridge rail, with joints riveted to a joint plate, which constituted a fished joint. The making an accurate bed for the joint plate was troublesome; no difficulty was experienced in riveting the rails to the plates. Subsequently he had abandoned the bridge rail, and had returned to the old form of the contractors' rail, which he believed to be the best kind of rail for this description of road. The rail he was now using was 4 inches in depth, 6 inches in width at the foot, and weighed 78 lbs. to the yard. This rail was simply bolted to longitudinal timbers, (the base being sufficiently wide to admit of bolts passing through it,) into which cross transoms were tenoned, the gauge being further maintained by tie-bolts $\frac{7}{8}$ths of an inch in diameter. A piece of steel $\frac{1}{8}$th of an inch in thickness, bent up at the edges, was placed on the longitudinal timber, at each joint; and bolts were passed through the rail, the steel plate, and the timber. The contractors' form of rail possessed several advantages over the bridge rail. The metal was better disposed for carrying weight, and such a rail was much stiffer than a bridge rail with the same weight of iron. It was easily laid, no chairs were required, and "fishes" could be used. It was difficult to roll, of the dimensions above given, and on this account great care had to be taken in its manufacture, and the best metal only could be employed. The longitudinal system might be a little safer than the transverse sleeper road, as there was not the same risk arising from broken rails, or of the keys escaping from the chairs. It required, however, better ballast, and there was not the same facility for putting in points and crossings, on which account it was not quite so well suited for a mineral district. Both plans were very good if treated properly, and there was scarcely a choice between them.

The contractors' form of rail, $5\frac{1}{2}$ inches in depth, and weighing 62 lbs. to the yard, had been much used on the Prussian railways.

It was fastened by "dogs" to cross sleepers, each 10 inches, or 12 inches wide, and placed 3 feet apart. The ballast was undoubtedly good, in fact no bad ballast was allowed to be used. The joints were "fished," and great care was taken in laying, especially in adjusting the elevation of the outer rail on curves; in this respect comparing favourably with the practice in England, for after all the trouble and expense incurred in constructing railways in this country, the permanent way was sometimes laid too hurriedly. He had travelled over the Prussian lines at a speed of 40 miles an hour, and the road appeared to stand remarkably well. The engines were not, however, so heavy as in England.

Mr. E. PRICE stated, that in Egypt, with Greaves' cast-iron sleepers, three miles of permanent way had been laid and made good in a week. In the Brazils, with the Barlow rail, not more than one mile and a-half had hitherto been completed in a week.

It might interest the Members to learn the simple method he had devised for laying a line with Greaves' cast-iron sleepers. As originally used, in 1851, on the Lancashire and Yorkshire Railway, the sleepers, or bells, when placed in position were filled with earth, through a small hole at the top, only about 4 inches in diameter. This occupied considerable time, and it was doubtful whether the process was complete.

With a view of increasing the rapidity of construction, and of rendering the filling of the "bells" certain, he had adopted a light framework, to the underside of which six light, outline bells, or sleepers, were attached at the proper distances apart, both longitudinally and transversely. These outline bells had openings at the top, sufficiently large to allow the earth to be filled in with a shovel, and to be thoroughly consolidated with an iron rammer. When this was complete the framework was lifted off, and moved on in advance, so that the work was continued in regular order, little mounds of earth being left of the shape of the inside of the regular sleepers, which were then dropped into their places, and the rails fitted to them. He had at first thought, that there might be some difficulty in carrying out this plan on curves, but the framework had been found capable of being adjusted to any curve, with the greatest nicety, so that these parts of the line became as simple as any other. By that plan the work was much facilitated, whilst a saving was effected of between £30 and £40 per mile in the laying, in addition to the increased rate at which the work was performed. In fact, from laying forty pairs of rails per day they arrived at eighty pairs of rails per day.

Mr. G. BERKLEY stated, that Greaves' sleepers had been used with satisfactory results on the Great Indian Peninsula Railway. He concurred in the opinion, that the contractors' rail was a better and a stronger form than the bridge rail. A consideration of the

subject led him to suggest, whether it was not also a very good form of rail to be used with chairs and cross sleepers. It appeared to him, that one great want in the latter kind of road was bearing surface for the rail on the chair. This the contractors' form of rail would supply, and to such an extent as, perhaps, to compensate for the capability of reversal, possessed by the double-headed rail.

Mr. BRUFF said, it would appear from the superior dimensions of the sleepers used on the Prussian lines, that nearly double the bearing surface was afforded to the rails, as compared with the ordinary half-round sleepers used in England. The rail which came nearest, in dimensions and economy of material, to that described by Mr. Hawkshaw, was that laid on the Eastern Counties Colchester line, in 1839-40, which was perhaps the deepest and the thinnest that had ever been used. It weighed 75 lbs. to the yard. The chairs were very small, and the intermediate, as well as the joint sleepers were all laid 5 feet apart. This road had remained in a satisfactory condition up to the present time, and he was not aware of a single accident having ever occurred on that portion of the Company's line, from the failure of the permanent way; but, a few years back, it was deemed advisable to introduce additional intermediate sleepers.

On the Haddiscoe and Halesworth line, where there was some heavy traffic, though as a rule it was light, the rails were of the bridge form, light but deep, and laid upon cross sleepers. A plate was used at the joints, turned up at the sides to form a clip, to prevent the ends of the rails from moving laterally. There was a square hole in this plate, and a corresponding slotway in the bottom flange of the rail, to admit of a dog-spike being driven, to secure both the rail and the plate to the sleeper. Though this description of permanent way appeared to stand well, it was obvious that the form of rail was not the best suited for a cross-sleeper road. It formed, however, a cheap road, and he understood that it was maintained at small cost.

In restoring the works upon the Eastern Counties lines, he had found the keys generally so decayed, that in many cases they could be picked out by hand; and had there been any material lateral strain, the road must have gone to pieces. He had no doubt, that much more importance had been attached to the supposed lateral strain than it was entitled to.

Mr. STRAPP remarked, that on the London and South-Western Railway, there were still 25 or 30 miles of line with 5 feet bearings, and it was astonishing to see the way in which it stood, having regard to the weight of the engines and the speed of the trains. Portions of the line had been relaid with longitudinal timbers, owing to there being a large stock of bridge rails on hand.

He considered that the latter system was more difficult to repair, and that the first cost was much greater than was the case with cross-sleeper roads.

Mr. DOYNE had laid the contractors' form of rail upon some short mineral lines in South Wales, where the gradients were in some cases 1 in 40, and the curves were never better than 10 chains radius. The traffic was carried on with heavy locomotives. The rail was about 4½ inches in depth, and from 3¼ inches to 3½ inches in width at the base, laid on transverse sleepers, and fastened with "dogs." The joints were "fished," and laid upon a flat plate ⅜ths of an inch thick, let into the sleeper. He had no opportunity of judging of the results beyond about 12 months after the line was opened; then it was an excellent road, and he had not observed any tendency to overturn, from the great height compared with the small base of the rail.

Mr. BEARDMORE believed, that in Ireland bridge rails were very generally used, with cross sleepers, having grooves to receive the rails, cut by a machine to give the requisite gauge and inclination. On several branch lines in that country, which had recently come under his notice, the common "dog" bolt was used for fastening the rails, and a growing feeling of preference was arising for the contractors' rail over the bridge rail, as with the former the most judicious form of "fish," in its original, simple form, could be adopted. The "dog" bolt appeared to answer very well, although at first sight it did not seem equal to the bolt going through the sleeper with the nut below, which had been much employed in Ireland.

Mr. J. S. VALENTINE doubted the advantage of the contractors' form of rail, weighing 78 lbs. to the yard, and laid upon cross sleepers, over the ordinary single-headed rail weighing 60 lbs. to the yard, fixed in chairs. The cost in the two cases would be about the same. Single-headed rails, 5 inches in depth, had been laid on the Rugby and Stamford, and the Eastern Counties and the Stour Valley lines.

Mr. J. G. C. CURTIS said, in Spain, where there was a deficiency of skilful workmen, the form of rail found to answer best, was the American bridge rail, laid upon transverse sleepers, and fastened with "dogs."

Mr. SANDERSON inquired what description of ballast was used on the Grandes Landes road. If it was broken stone, the permanent way might answer, but on gravel, or clay, it would not do at all. The "Barlow" rail did not succeed so well upon light ballast, as it did upon broken stone; and when laid in warm climates, it had been found to buckle at the joints, when any great length was riveted. This was also the case with "fished" rails. The bridge rail, whether laid upon longitudinal, or upon trans-

verse sleepers, was preferable under such circumstances, because it afforded greater opportunity for expansion and contraction.

Mr. SMITH explained, that there was no broken stone ballast on the Grandes Landes line. He added that there was great difficulty in preserving the gauge.

Mr. E. PRICE said, he had found no difficulty in laying a length of 14 miles of Barlow rail in the Brazils. The expansion and contraction did not depend on the intensity of the temperature, but upon the variations of the climate. The bolt-holes were oval in form, and allowed a little play.

Mr. C. MAY inquired, whether any great quantity of the contractors' form of rail of the dimensions stated had been rolled? Although many things said to be impossible could be accomplished, yet in this case there was this practical difficulty—that, inasmuch as, being rolled edgeways, they cut 3 inches into a roll of 20 inches diameter, the manipulation was difficult; and the drag of the rolls, from the unequal diameter of the grooves, was considerable, tending to make the rails imperfect at the edges.

Mr. HAWKSHAW stated, that 20 miles of these rails had been rolled already, and they were amongst the best he had used. At the same time, there was the difficulty which had been suggested; one advantage was that the manufacturers could not use any other than the best iron for the purpose.

He thought it would be a very useful addition to this subject, if some one would furnish an account of the value of the angular motion, in reference to rails of different heights, applied to various curves, with different weights of engines, at different velocities.

Mr. BABBAGE thought it might be useful to mention a Paper connected with this subject, the title of which was "Mémoire sur les limites des vitesses qu'on peut imprimer aux trains des chemins de fer, sans avoir à craindre la rupture des rails," par M. Mahistre.[1] The experiments on which the calculations were founded, were made at Portsmouth, on the flexure of railway bars, over which carriages passed with various velocities. These experiments had also been reported upon and discussed by General Morin.[2]

Having made this reference, Mr. Babbage was unwilling to sit down, without expressing his delight at the manner in which the discussion had been carried on: each gentleman who had addressed the Meeting having contributed the valuable result of his own practical experience bearing upon the subject of the Paper, to the great advantage of the science of engineering.

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[1] *Vide* "Comptes Rendus de l'Académie des Sciences." No. 12. March 23, 1857.

[2] *Vide* "Traité de la Resistance des Matériaux." De M. le General Morin. 2e edition, p. 364.

Mr. BIDDER, V.P., observed, from the remarks which had been made, it might be gathered, that with good materials, it would be difficult not to lay a safe road. The kind of system to be adopted must always depend, in a great degree, upon purely local considerations; on the superior facilities for obtaining timber, or iron, and on the comparative cost of the two, as well as on the climate, and on other conditions. The greatest difficulties would be encountered in those countries liable to extreme variations of temperature, as in Canada and Norway, where at times they were subject to almost tropical heat, and at others the temperature was 30 degrees below zero. In Norway they were exposed to another phenomenon, when the frost left the ground in the spring. The frost penetrated to a depth of from 4 feet to 5 feet, and this mass of earth was sometimes lifted bodily from 3 inches to 6 inches, and so suddenly, that, on one occasion, seven miles of fencing had been thrown down in a short time. Being aware of this, and although, in general, in favour of cross sleepers, he had adopted, on a railway in that country, longitudinal timbers, laid again on cross sleepers, as timber was very plentiful, with a bridge rail of about 60 lbs. to the yard. At first the joint plates were simply laid on the longitudinal timbers, and allowed gradually to make a bed for themselves. In the succeeding summer, the plates were heated, and were allowed to burn themselves into the timber. Every precaution had been taken to make the road sufficiently rigid to hold together, so as to be passable during the whole of the winter, without requiring any repairs. Hitherto the success had been complete, for no interruptions had arisen, to the regular passage of the trains, from the climate. The system practised in Norway, and also in Denmark, with so much success, had been followed in Canada, but for some unaccountable reason, it had suffered "official" condemnation.

There was much truth in the observation, that sufficient attention was frequently not paid to the final finishing of the road. Enormous expense was incurred in levelling the country, excavating, tunnelling, and embanking, whilst the final completion was sometimes done in a way that was not creditable. The Directors fixed a time for the opening, and it was often impossible to have such workmanship, in the laying of the road, as was desirable. In addition to care in laying the permanent way, it was desirable to adopt such a description of rail as would necessitate the employment of a good material in the manufacture.

In accordance with the notice on the card of the meetings, it was resolved to adjourn for a fortnight, in order to avoid holding a meeting on Easter Tuesday, April 14th.

April 21, 1857.

GEORGE PARKER BIDDER, Vice-President, in the Chair.

No. 956.—"On Electro-Magnetism as a Motive Power."[1] By ROBERT HUNT, F.R.S.

THE application of Electro-Magnetism, as a motive power, has repeatedly engaged the attention of ingenious minds. Long-enduring thought has been brought to bear upon the subject, and large sums of money have been expended in the construction of machines;—yet there does not, up to the present time, appear to be any nearer approach to a satisfactory result, than there was thirty years ago. The idea that a Force so powerful as Electricity might be made to supersede Heat, as a source of Mechanical power, has in it something peculiarly attractive, and hence men still continue to exercise their ingenuity, in attempting the solution of this problem.

Having on various occasions devoted much time and thought to this matter—and, aided by the investigations of others in support of his own experiments having arrived at some conclusions, which may possibly serve to guide new inquirers, the Author ventures to submit them to the consideration of the Institution of Civil Engineers.

It will be necessary to the correct understanding of the subject, that the phenomena which are exhibited in Electro-Magnetic actions should be briefly, but clearly explained.

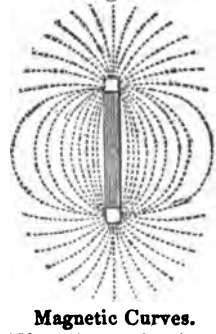
In 1819, Professor Oersted, of Copenhagen, made his famous discovery, that when a magnetic needle was placed near the conducting medium of a voltaic arrangement,—such as a copper wire,—it was immediately deflected, from its natural position, and took up a new one, which was regulated by the relative forces of the needle and the wire.

When a wire was made the connecting band between the terminal plates of any voltaic arrangement, the Electrical disturbance which was commenced by the chemical action in the battery, was communicated as a series of pulsations called a current, to, and passed through, or along, the wire. Experiment has shown, that the force called Magnetism is exerted around a magnetised bar of steel, along certain lines which are beautifully

[1] The discussion upon this Paper occupied a portion of two evenings; but an abstract of the whole is given consecutively.

indicated when iron filings are sprinkled over a piece of paper, stretched above a magnet. (Fig. 1.) These lines are known as "Magnetic curves" or, as Faraday expresses it, "the curved lines of Magnetic force." From the conducting wire a similar exhibition of lateral force can be detected. Therefore, when the permanent magnetic bar is brought near to the excited wire, by the combined influences of those two sets of forces, they are compelled to place themselves at right angles to each other. If the magnet was fixed and the wire free to move, the latter would arrange itself across the magnet; but the magnet being free, and the wire fixed, the magnet is forced from its natural position, in relation to the Earth's Magnetism, and, in obedience to the Electric excitation, places itself at right angles to the wire.

Fig. 1.

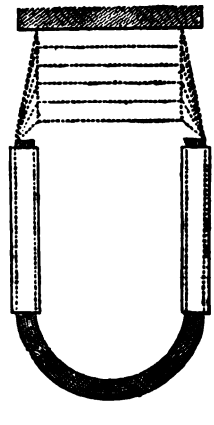


Magnetic Curves.

From this remarkable discovery a speedy advance a few steps farther was made. It is not necessary to follow the induction through all its stages, it being sufficient to state, that a piece of soft iron being coiled round with covered copper wire, became a magnet, whenever an Electric current circulated through that wire. In this way there was generated in bars of soft iron an enormous lifting power.

If a bar of iron be bent into the form of the letter U, or of a horse-shoe, (Fig. 2,) and there is coiled around the arms a considerable

Fig. 2.



quantity of copper wire clothed with silk or cotton, or coated with resin, or gutta-percha, there is formed an Electro-magnet of the best form for developing the lifting power which is generated by

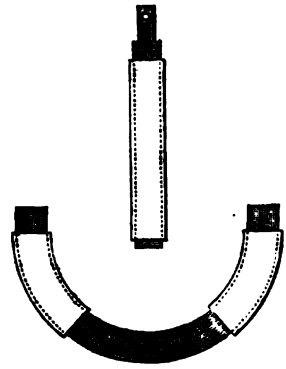
the circulation of an electric current around it. If an armature of iron is placed on the poles, and the wires are connected with a voltaic battery, this magnet will be capable of sustaining many tons weight. When connection is broken with the battery, the bar of iron immediately loses its sustaining power, and returns nearly to its normal state. If the iron is not perfectly pure a small amount of magnetic force is always retained; but for all practical purposes, the bar may be said to cease to be magnetic, when the current is interrupted.

Thus it was rendered apparent, that at any moment, by a very simple arrangement, an almost unlimited amount of power could be generated, and be as readily destroyed. Beyond this, it was easy to change the direction in which the Electric current circulated, and thus to convert that point of the iron, which was a north pole, into a south pole, and the south, in like manner, into a north pole. It had long been known, that the dissimilar poles of magnets attracted each other, with a force equal to the sum of their two powers, and that similar poles repelled each other. All attempts which have been made to apply this force for the purpose of moving machinery, have been dependent upon the attracting and repelling powers of such a polar arrangement as that described. Investigations were not wanting to determine the best form of the magnets, the length of the arms, and the quantity of wire necessary to produce the highest effect. On the present occasion it is not necessary to enter into any details upon these points; but it will be supposed that the most perfect electro-magnets have been made and used in the construction of electro-magnetic engines.

Numerous electro-magnetic machines have been made, but a few only of these require to be described. In 1832, Salvatore Dal Negro published an account of the attempts made by him in this direction. As Dal Negro's engine was of a very simple and effective kind, the Professor's description of it may be quoted:— "As I had been successful in producing temporary magnets of very great power, with very small electromoters, I endeavoured to apply this power to moving machinery. I will now briefly state by what means I endeavoured to set a lever in motion. I first used a magnetic steel bar, placed vertically between one end of a temporary magnet. The bar vibrated from the attractions and repulsions which took place between its north pole and the north and south poles of the electro-magnet. In the same way a motion may be effected in a horizontal plane. I also set in motion a similar bar, by allowing a piece of iron, set free from the magnet at the moment when its power became = 0, to fall on one of its ends, after this it was immediately re-attracted. This can be effected in two ways: the one may be employed when a quick motion is to be produced, and the second when a greater force is wanted; in the

first case the weight falls only just out of the power of the magnet's attraction, and the instant the weight has fallen upon the bar, or lever, it is re-attracted by the magnet, that the action may be repeated: it is always small in comparison with that which the magnet can support, whilst in contact. In the second case the whole weight which the magnet can carry is employed, and use is made of the force which draws it to the magnet." Fig. 3 represents a type of Dal Negro's engine. Upon this was founded several other attempts, particularly one by Dr. Schulthess, who was so satisfied with the result, that he wrote in 1833:— "If we consider, that electro-magnets have already been made, which were capable of carrying 20 cwts., and that there is no reason to doubt, that they may be made infinitely more powerful, I think I may boldly assert, that electro-magnetism may certainly be employed for the purpose of moving machines." Professor Botto, of Turin, also employed "a lever put in motion (in the manner of a metronome) by the alternating of two fixed electro-magnetic cylinders, exerted on a third moveable cylinder, connected with the lower arm of the lever, the upper part of which maintains a metallic wheel, serving in the ordinary way, as a regulator, in a continuous gyratory motion." It will be evident to any one who has observed the motion of many of the electric clocks, that this is in several respects similar to the pendulous motions adopted. Fig. 4 is a type of Botto's machine.

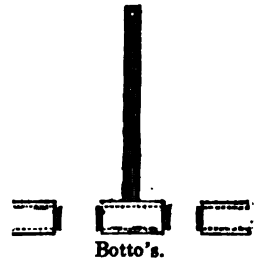
Fig. 3.



Dal Negro's.

In 1835, Professor Jacobi, of St. Petersburg, published an account of his experiments, which were carried out on a large scale, regardless of cost, at the expense of the Emperor Nicholas. His first idea was to employ the attractive and repellant powers of magnetic bars, so that he might obtain an advancing and receding motion, which could be easily changed into a continuous circular motion. A great many machines have been made upon this principle; but Jacobi, alone, as far as can be learned, has pointed out the true cause of their failure. "We know," he says, "the ill effects of shocks in the movements of machines, but there is here another inconvenience, which is not simply mechanical. The soft iron by these repeated shocks and vibrations, gradually acquires at

Fig. 4.

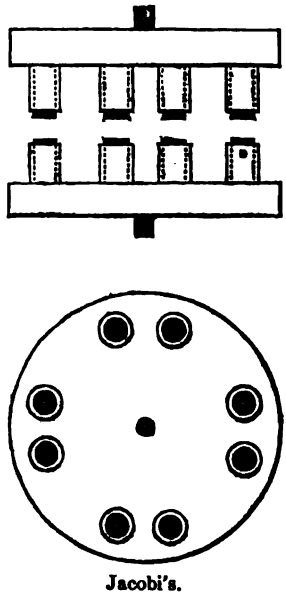


Botto's.

the surface of contact the nature of steel; there will be a considerable permanent magnetism, and the transient magnetic force, which alone produces the movement, will be weakened in proportion. A number of experiments, which I have made upon the magnetic force of a bar of soft iron, bent into a horseshoe form, has shown me the great disadvantage of often repeated shocks, proceeding from the sudden contact of the armature."

Jacobi, finally setting aside all oscillating motions, produced a machine giving continuous circular motion, by fixing eight electro-magnetic bars on a disc, moveable round an axis—and eight fixed bars similarly arranged upon a fixed platform. Fig. 5. The arrangement of the bars admitted of much variety, provided it was exactly symmetrical, and that it allowed the poles to approach each other as nearly as possible. Arrangements were made, with much ingenuity, by which the poles of the magnets were inversed directly, and, so that that inversion should take place precisely at that point where the bars were opposite each other. One hundred and forty-four inversions in the second were readily effected, and Jacobi declared it would be easy with his apparatus "to change, or to completely interrupt, the electric current one thousand, or more, times in a second."

Fig. 5.



Jacobi's.

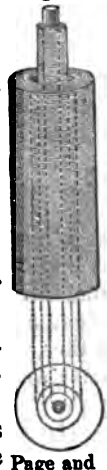
A machine constructed upon this principle was, at the desire and at the cost of an Imperial commission, put on board a ten-oared shallop, equipped with paddle-wheels, to which the electro-magnetic engine communicated motion. The boat was 28 feet long, and 7½ feet in width, and drew 2½ feet of water. In general, there were ten, or twelve persons on board, and the voyage on the Neva was continued during several entire days. By these experiments Jacobi was led to the conclusion, that a battery of 20 square feet of platinum would produce power equivalent to one horse; and the vessel went at the rate of four miles an hour. In 1839, Jacobi tried another experiment, with a battery of sixty-four platinum plates, each having 36 square inches of surface; when the boat, with a party of fourteen persons on board, went against the stream at the rate of three miles an hour.

In 1837, Mr. Thomas Davenport, of the United States, constructed a rotary engine, in which permanent and electro-magnets

were employed. Mr. Taylor, in 1839, patented an electro-magnetic engine, both in America and in this country, the principal novelty in which was, that instead of changing the poles of the magnets, the electric action was, at fixed rapid intervals, entirely suspended. In 1837, Mr. Davidson, of Edinburgh, constructed an engine, in which he produced motion by simply suspending the magnetism, without a change of the poles. Mr. Robert Davidson placed an electro-magnetic locomotive on the Edinburgh and Glasgow Railway; the carriage was 16 feet long, and 6 feet broad, and weighed about 5 tons. All the arrangements appear to have been very complete, but when put in motion on the rails, it was not possible to obtain a greater speed than four miles an hour.

Professor Page's electro-magnetic engine (Fig. 6.) was for some time looked upon as a triumph. The fundamental principle of it is thus described: "It is well known, that when a helix of suitable power is connected with the poles of a battery in action, an iron bar, within it, will remain held up by the induced magnetism, although the helix be placed in a vertical position; and if the bar is partly drawn out of the helix by the hand, it goes back with a spring, when the hand lets go its hold. This power, the action of the helix upon the metallic bar within it, is the power used in Page's engine." Professor Page exhibited one of his engines, of between 4 and 5 horse-power, at the Smithsonian Institution; the battery, to operate with, being contained within a space of 3 cubic feet. It was a reciprocating engine of 2 feet stroke, and the whole, including the battery, weighed about one ton. Professor Page stated, that the consumption of 3 lbs. of zinc per day would produce one horse-power. This statement requires further investigation.

Fig. 6.



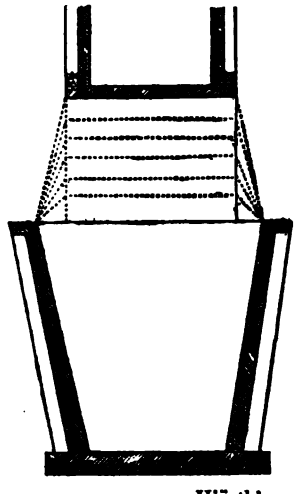
Page and Hjörth's.

Many similar attempts have been made, to construct effective machines to be moved by the power of the voltaic battery. Among others, Mr. Henley constructed an electro-magnetic engine of considerable power, for Mr. Talbot, and another for Professor Wheatstone. In these there were many ingenious mechanical arrangements, invented to overcome some of the difficulties hitherto encountered; but the physical conditions were similar to those already described. Mr. Talbot's engine was 3 feet 6 inches long, and 2 feet 6 inches wide; when excited by a Grove's battery, consisting of four cells with double plates of zinc 9 inches by 6½ inches, platinum plates 9 inches by 5½ inches, excited by diluted sulphuric acid in the proportions of 1 to 4, and concentrated nitric acid, it drove a lathe, with which was turned a gun-metal pulley 5 inches in diameter; but in three-quarters of an hour the battery was quite exhausted.

Mr. Hjörth, a few years since, exhibited in London a large

machine, constructed somewhat on the principle of Page's (Fig. 7);

Fig. 7.



Hjörth's.

this, however, failed to produce any great mechanical effect, and it appears to have been abandoned. Dr. Lardner stated, in 1851, that M. Gustave Froment, of Paris, was using, with much advantage, an electro-magnetic engine in his workshops for turning lathes, planing machines, &c. That use, however, appears to have been abandoned, on account of the great cost of the battery power.

Hankel and Fessel, on the Continent, the Rev. James William M'Gauley, Dr. Kemp, and others, in Great Britain, have, at different times, excited much attention, by the ingenious machines which they have constructed.

Notwithstanding these numerous trials, and, connected with them, an almost infinite amount of experiment, it does not appear, that any satisfactory explanation has ever been given, of the causes which have led to the abandonment of the idea of employing electricity as a motive power. It is mainly with the view of directing attention to these causes, that the present communication has been written.

Electro-magnetism undoubtedly affords an almost unlimited power. An electro-magnet may be constructed which shall have a lifting power equal to many tons. It is probable, that there are limits beyond which it would not be possible to increase the power of electro-magnets; those limits have not yet been reached; but

supposing them to be attained, there is nothing to prevent the multiplying of the number of electro-magnets in the arrangements. It may be stated, in connection with this part of the subject, that from experiments made with Hearder's magnetometer, it appears that the development of magnetism in iron observes some special peculiarities. These may be thus stated:—With the same electro-magnet there is, as the voltaic pairs in the battery are increased, a gradual increase of magnetic force. With from one to seven elements there appears an average excess of 31 lbs.; after this point, with the increase of battery power, by the addition of pair after pair of zinc and platinum elements, the production of power bears a decreasing ratio to the power employed, and at last, the addition of five elements was not found to produce an increase of effect equivalent to the value of one element. In all experiments, therefore, on electro-magnetic machines, the experimentalist has first to determine the utmost power which the soft iron is capable of assuming, in relation to,—1st. The number of coils of wire on the iron; and 2nd, The number of elements employed in the exciting source—the voltaic battery. The length of the iron and its thickness are also points demanding special considerations from the constructor of an electro-magnetic machine. Supposing, however, that the best possible conditions have been secured, and that electro-magnets are produced, giving the maximum effect, with the most economical results, in the exciting battery; the following difficulties still remain to be dealt with:—

All long-continued experiments have tended to show, as was stated by Jacobi, that the direct attracting and repelling powers of magnets,—that is, the direct drawing and pushing force,—cannot be applied: this arises from the fact, that the molecular change, which is produced by the continued vibratory action of the rapid succession of blows received by the iron, renders it eventually so hard, as to cause it to retain considerable magnetic force. By this, the mechanical power required is constantly diminishing, until, at last, it is nearly destroyed. Some such arrangements as those which have been described, become necessary; where magnets fixed on an axis are made to revolve immediately in front of other magnets, fixed in a circle,—or the contrary. A certain distance must be maintained between the poles of the moving and the fixed magnet, and with this distance there is a considerable diminution of the power of the magnets. From a series of carefully-made experiments in which a steel-yard was employed, by which the attractive power of the magnets at slightly-varying distances, could be weighed off, a large number of results were obtained, which are fairly represented by the following summary:—(See also Fig. 2).

When the armature was in contact with the electro-magnet, the force required to separate it was	220 lbs.
At the distance of $\frac{1}{250}$th of an inch . .	90 „
„ $\frac{1}{125}$th „ . .	50 „
„ $\frac{1}{84}$th „ . .	47 „
„ $\frac{1}{63}$th „ . .	40 „
„ $\frac{1}{50}$th „ . .	36 „

A series of results obtained by Mr. Hjörth with the large electro-magnetic machine which he constructed, (Fig. 7) showed that,—

At 1 inch the attractive force was . .	160 lbs.
„ $1\frac{1}{2}$ „ „ . .	140 „
„ $2\frac{1}{4}$ „ „ . .	124 „
„ 3 „ „ . .	88 „
„ 4 „ „ . .	80 „
„ 5 „ „ . .	72 „

It will be noticed, that in the Author's own experiments, the differences are those observed between actual contact and the distance of $\frac{1}{50}$th of an inch, but the actual working difference may, with more propriety, be calculated as between 90 lbs. and 36 lbs. Mr. Hjörth's engine, it will be remembered, was one attracting an electro-magnetic piston into an electro-magnetic cylinder, so that the pulling force commenced at the minimum and gradually rose to the maximum,—when the poles being reversed, the order of action was changed. Both those results are instructive, as showing the loss of electro-mechanical force through space. They show also, that if an electro-dynamic arrangement is made, the magnets included in which shall have the power of supporting upwards of a ton weight each, disappointment will ensue, if it is expected to realize one-half that power in the mechanical effects of that force. It would not be advisable to construct any machine, the moving parts of which were brought nearer together than the $\frac{1}{50}$th of an inch. Now, it has been shown, that the attractive power of a magnet at $\frac{1}{50}$th of an inch distant from its poles, is less than half what it was at the $\frac{1}{250}$th of an inch. Beyond this there are, also, some other points to which sufficient attention has not been paid, by those who have been engaged in the construction of electro-magnetic machines.

It is now well known, to all who have paid any attention to the phenomena of electro-magnetism, or of magneto-electricity, that whether the armature be moved in front of the poles of a magnet, or the magnet in front of a fixed armature, or if both be moved together in opposite directions, a considerable amount of disturb-

ance is the result. If a proper arrangement is made, it results that there will be thus generated, by induction, another form of force—that is, the magneto-static force will be re-converted into an electro-dynamical force. In all electro-magnetic engines, some parts must be in motion. The magnets, on the moving parts of the machines, must move either to and from other magnets, or, in the case of circular motion, in front of them. Now experiments on both large and small machines have proved, that the power of an electro-magnetic machine, in motion, is much less than the power of the same machine at rest; and as the rate of motion is increased, the available power as regularly diminishes. In confirmation of the Author's own investigations upon this point, he must refer to the published Papers by Jacobi, Dal Negro, those by Messrs. Joule and Scoresby, and to the report of the engineers on Page's engines, in the United States.

The following Tables show the effects of motion upon the force of the current circulating the wires coiled around an electro-magnet,—when the magnet was at rest, and when in motion,—and the attractive force of the magnet itself, both when in repose and when moving:—

FORCE OF CURRENT IN ELECTRO-MAGNET.

At Rest.	In Motion.
2,232 lbs.	920 lbs.
2,232 ,,	850 ,,
1,381 ,,	850 ,,
1,381 ,,	678 ,,
2,081 ,,	1,300 ,,
2,035 ,,	1,000 ,,

The results here given may not appear consistent with each other; it is, therefore, necessary to explain, that they have been purposely obtained under different conditions, as regards the excitants employed in the battery, the temperature, and the rates of motion. In every case there was experienced a considerable reduction of the force of the current, a loss, indeed, of mechanical power, the moment the magnets were put in motion, the attractive force of the magnets being influenced in the same way, as shown in the following results:—

ATTRACTIVE FORCE OF MAGNET.

At Rest.	In Motion.
150 lbs.	75 lbs.
143 ,,	70 ,,
120 ,,	68 ,,
75 ,,	31 ,,
30 ,,	14 ,,
15 ,,	10 ,,

Present experience in electro-magnetic machines shows, that other causes act in reducing the available power of the force. In the report on Page's engine it was stated, that the greater the velocity at which the engine was driven, the less was its mechanical power. As the rate of motion was steadily increasing, the available force was gradually reducing, the work done becoming smaller, where it was expected a large increase of duty would have been the result.

Beyond the reduction of the force of the current and the diminishing attractive force of the magnets, induced electric currents have to be dealt with, which, having a tendency to circulate in directions opposite to those which are being employed, produce considerable disturbance in the arrangements. Those currents were detected by Jacobi; and Mr. Hjörth stated, that in some large experiments made at Liverpool, he endeavoured to render this induced electricity available, but without any satisfactory result.

The chief causes which have frustrated the endeavours to apply electricity as a motive power have been noticed. All electro-magnetic arrangements suffer from the causes named, a reduction of the mechanical value of the prime mover, in a manner which has no resemblance to any of the effects due to Heat, regarded as a motive power.

There remains now to examine the production of the power, electro-magnetism.

The electro mechanician is dependent upon his battery, in the same way as a steam engineer is dependent upon his fire and his boiler, for the production of mechanical effect.

Voltaic batteries vary in their effects, and hence arise statements which differ widely from each other, as to the result obtained, by the destruction (? change of form) of a given quantity of metal in the battery.

Dr. Botto states, that 45 lbs. of zinc, consumed in a Grove's battery, are sufficient to work a one-horse power electro-magnetic engine for twenty-four hours.

Mr. Joule says the same results would have been obtained, had a Daniell's battery been used, by the consumption of 75 lbs. of zinc.

It is impossible, on the present occasion, to enter into the theory of the voltaic battery, or to describe the varieties of arrangement which have been adopted for generating (developing) electrical force in the form of a current, with the greatest effect, at the smallest cost.

On this point the evidence of Jacobi may be quoted:—"With regard to the magnetic machine, it will be of great importance to weaken the effects of the counter current, without at the same time weakening the magnetism of the bars. It is the alternate com-

bination of the pairs of plates in the voltaic pile, which permits us to increase the speed of rotation at will. We know the magnetic power of the current is not sensibly augmented by increasing the number of the pairs of plates, but the counter current is considerably weakened by its being forced to pass through a great many layers of liquid. In fact, on using twelve voltaic pairs, each, half a square foot, instead of four copper troughs, each, with a surface of two square feet, which I had hitherto used, the speed of rotation rose at least 250, or 300 revolutions in a minute."

Mechanical force, whether obtained in the form of man-power, horse-power, steam-power, or electrical-power, is the result of a change of form in matter. In the animal, it is the result of muscular and nervous energy, which is maintained by the due supply of food to the stomach. In the steam-engine, it is the result of vapour pressure, which is kept up by the constant addition of fuel to the fires under the boilers. In the magnetic machine, it is the result of currents circulating through wires, and these currents are directly dependent upon the chemical change of zinc or of some other metal in the battery. Then,

Animal power depends on food.
Steam power depends on coal.
Electrical power depends on zinc.

An equivalent of coal is consumed in the furnace—that is, it unites its carbon with oxygen to form carbonic acid, and its hydrogen with oxygen to form water, and during this change of state the quantity of heat developed has a constant relation to the chemical action going on.

Mr. Joule has proved by a series of most satisfactory experiments, that: "The quantity of heat capable of increasing the temperature of a pound of water by one degree of Fahrenheit's scale is equal to, and may be converted into, a mechanical force capable of raising 838 lbs. to the perpendicular height of one foot."

Quoting Mr. J. Scott Russell, Mr. Joule proceeds: "From these facts it appears, that in the Cornish boilers, at Huel Towan, and the United Mines, the combustion of one pound of Welch coal gives 180° to a cubic foot of water, or otherwise 11,437° to a pound of water. But we have shown, that one degree is equal to 838 lbs. raised to the height of one foot. Therefore the heat evolved by the combustion of one pound of coal is equivalent to the mechanical force capable of raising 9,584,206 lbs. to the height of one foot, or to about ten times the duty of the best Cornish engines."

Such are the conditions under which heat is employed as a motive power. An equivalent of zinc is acted on by the acid in

the cells of the battery, and is oxidized thereby. In this process of oxidation a given quantity of electricity is set in motion; but the quantity available for use, falls very far below the whole amount developed by the oxidation of the zinc. The electricity, or electrical disturbance, is generated on the surface of the zinc; it passes through the acidulated fluid to the copper plate, or platina plate, and in thus passing from one medium to another, it has to overcome certain mechanical resistances, and thus a portion of the force is lost. This takes place in every cell of the voltaic arrangement, and consequently the proportion of zinc which is consumed, to produce any final mechanical result, is considerably greater than it should be, theoretically.

Joule gives as the results of his experiments, the mechanical force of the current produced in a Daniell's battery as equal to 1,106,160 lbs. raised one foot high, per pound of zinc, and that produced in a Grove's battery as equal to 1,843,600 lbs. raised one foot high, per pound of zinc.

It need scarcely be stated, that this is infinitely above what can be practically obtained. A great number of experiments, made by the Author some years since, enabled him to determine, as the mean average result of the currents, produced by several forms of battery power, that one grain of zinc, consumed in the battery, would exert a force equal to lifting 86 lbs. one foot high. Mr. Joule and Dr. Scoresby thus sum up a series of experimental results: "Upon the whole, we feel ourselves justified in fixing the maximum available duty of an electro-magnetic engine, worked by a Daniell's battery, at 80 lbs. raised a foot high, for each grain of zinc consumed." This is about one-half the theoretical maximum duty. In the Cornish engines, doing the best duty, one grain of coal raised 143 lbs., one foot high. The difference in the cost of zinc and coal need scarcely be remarked on. The present price of the metal is £35 per ton, and coal can be obtained, including carriage to the engines, at less than £1 per ton; and the carbon element does two-thirds more work than can possibly be obtained from the metallic one.

By improving the battery arrangements, operators may eventually succeed in getting a greater available electrical force. But it must not be forgotten, that the development of any physical force observes a constant law. Whether in burning coal in the furnace, or zinc, or iron in the battery, the chemical equivalent represents the theoretical mechanical power. Therefore, the atomic weight of the carbon atom being 6, and that of the zinc atom being 32, it is not practicable, under the best possible arrangements, to obtain anything like the same mechanical power from zinc which can be obtained from coal. Zinc burns at an elevated temperature; in burning a pound of zinc there should be obtained, as heat, the

same amount of mechanical power which is obtained as electricity in the battery. The heat being more easily applied as a prime mover, it would be far more economical to burn zinc under a boiler, and to use it for generating steam power, than to consume zinc in a voltaic battery for generating electro-magnetical power.

The Paper is illustrated by a series of Diagrams, from which Figs. 1 to 7 have been compiled.

[Professor WILLIAM THOMSON.

Professor WILLIAM THOMSON, (Glasgow,) through the SECRETARY, directed attention to the researches of Mr. J. P. Joule, on the subject of the economical production of mechanical effect from chemical forces, which appeared not to be sufficiently known to theoretical, or practical men generally, or even to those who had investigated that most interesting branch of electrical science.

In a series of papers in the "Philosophical Magazine,"[1] Mr. Joule had shown, by an able combination of theory with experiment, what the total mechanical effect, derivable from the consumption of a stated quantity of zinc, in any of the ordinary galvanic batteries, amounted to: and, in conjunction with the late Dr. Scoresby, he constructed an electro-magnetic engine, driven by a Daniell's battery, which actually performed more than 50 per cent. of the whole theoretical duty. The theoretical duty of a grain of zinc, used in a Daniell's battery, was 145 foot lbs., according to the dynamical deduction from Mr. Joule's most recent experiments on the thermal effects of electrolysis; a conclusion which was confirmed by direct experiments made by Professor Thomson, on the absolute electro-motive force of a single cell of that form of battery. Hence the engine referred to, (constructed by Mr. Joule and Dr. Scoresby,) which actually performed 80 foot lbs. of work per grain of zinc consumed, did 54 per cent. of the full duty. These facts were of the highest importance, in estimating the applicability of electro-magnetism, as a motive power, in practice; and indeed the researches alluded to, rendered the theory of the duty of electro-magnetic engines as complete as that of the duty of waterwheels was generally admitted to be. Among other conclusions that might be drawn from these experiments was this: that until some mode was invented, of producing electricity, as many times cheaper than that of an ordinary galvanic battery, as coal was cheaper than zinc, electro-magnetic engines could not supersede the steam engine. For, supposing an electro-magnetic engine to perform 75 per cent. of the theoretical duty, instead of the 54 per cent. obtained by Joule, then, such an engine, as near perfection as could be reasonably expected, would use 5 grains of zinc per horse-power per second, or 2·6 lbs. of zinc per horse-power per hour. A perfect electro-magnetic engine, driven by a Daniell's battery, would use 2 lbs. of zinc per horse-power per hour. Some of the best steam engines would perform 143 foot lbs. of work per grain of coal, or would use 2 lbs. of coal per horse-power per hour. In a scientific point of view, the electro-magnetic engine was most interesting,

[1] *Vide* "Philosophical Magazine," Dec. 1843, June 1846, and January 1853.

as having been the means of solving the problem of converting a large per centage of the whole energy of chemical forces (those of combination of zinc with oxygen and acid) into mechanical effect, without letting it into the form of heat at all; making, in fact, the combustion of zinc not generate more than 46 per cent. of its equivalent of heat, and directing it to raise weights, with the remaining 54 per cent. of its energy. But this very circumstance took away from its practical importance, since it showed how little could be expected from electro-magnetism, more than had been done by Joule and Scoresby. On the other hand, Joule's theory showed, that the full theoretical duty of the combustion of the coal was about eight times as much as had been obtained in the best steam-engines, and left a very wide margin for improvement in engines, deriving mechanical effect from coal fires. It ought, however, to be added, that although steam-engines fell so far short in the duty they rendered, for the consumption of the coal, the best steam-engines did, in reality, perform 50 or 60 per cent. of the duty of a perfect engine, taking in heat at the actual temperature of their boilers; and that to attain more than double, or even to attain as much as double, the present economy of a good steam-engine, it would be requisite to employ engines, taking in heat at a much higher temperature than the highest of the actual high-pressure boilers.

Mr. ROBERT HUNT desired to make a few remarks, in explanation of the circumstances, by which he was enabled to offer an opinion on this important problem. Some years ago, whilst he was engaged in the investigation of the subject of electro-magnetism as a motive power, accident brought him into contact with the late Mr. Benkhausen, then Russian Consul-General in this country. Having seen the apparatus which Mr. Hunt had prepared, in Cornwall, and having witnessed some of the experiments, Mr. Benkhausen expressed a wish that Mr. Hunt should communicate the results to Professor Jacobi, with whom, he eventually entered into a correspondence, through the Consul-General, and this induced an extended series of experiments, which were carried on at Falmouth. The results obtained, led him to the conclusions, stated in the Paper,—that electro-magnetism, as a motive power, could only be applied at a very disproportionate cost. At the meeting of the British Association, at Swansea, in 1848, he was applied to by some gentlemen, connected with the copper trade of that port, to make some further experiments on this subject. These gentlemen examined, with him, a boat propelled by electro-magnetism on the lake at Penllegaer, near Swansea, and were fully acquainted with the cost at which the power was obtained. They stated, that although electricity might cost thirty times as much as the power obtained from coal, it would nevertheless be sufficiently economical,

to induce its employment for the auxiliary screw ships, employed in the copper trade with South America. This led him to enter upon a fresh series of experiments, which confirmed the results previously obtained.

Another point which, perhaps, required further explanation than was given in the Paper, was the force of the current, with the magnet at rest and in motion. The mode in which these experiments were tried was this — An electro-magnet being fixed, its wires were so arranged, that they were carried on from the electro-magnet to a galvanometer: the permanent deflection of the galvanometer was first noted; then an armature, in the front of the magnet, was set in motion, to produce the disturbance he had mentioned, and the result was, that the force of the current was reduced, in the ratio represented in the Table (page 395). Thus in the first place, there was the loss of power which took place in space—for, although, when in contact, an enormous weight could be raised by the magnets, yet at an almost inappreciably short distance, the power was very considerably diminished: and to apply that, practically, when the magnet was in motion, led again to the loss of a considerable amount of the mechanical power.

Mr. W. R. GROVE remarked, that it was a long time since he had devoted close attention to the subject, and he had hoped, that in the thirteen years which had elapsed, since he lectured upon it at the Royal Institution, some more decided progress would have been made; but a practical application of the science appeared to be still distant. He believed, at the present time, the data which were regarded as the best on this subject were those of Professor Botto, of Turin, who estimated that, with a Grove's battery, there would be a consumption of 45 lbs. of zinc, per horse-power, exerted, per day. Page had stated the consumption to be only 3 lbs. per day, which was a matter (as was well remarked by the Author) requiring further investigation. He thought the quantity stated by Botto might be taken as the best approximation. Starting with this, and assuming a battery of one cell, the equivalent of zinc being 32, and $\frac{1}{3}$ of an equivalent of nitric acid being 18 ($\frac{1}{3}$rd of an equivalent of nitric acid being consumed in the battery for each equivalent of zinc), there would be consumed for 45 lbs. of zinc, 25·3 lbs. of nitric acid, which was equal to about 50·6 lbs. of commercial acid. Then, taking the zinc at threepence per lb. and nitric acid at sixpence per lb., and setting off the small quantity of mercury used for amalgamation, and the sulphuric acid, against the salts formed, the estimated cost would be £1. 16*s.* 7*d.* per horse-power for twenty-four hours. That was some approximation to the practical proposition to be come to, and it could not bear any comparison, as to economy, with the cost of steam power. Large allowances should, however,

be made for the approximative character of these results. Then came the theoretical difficulty of the equivalents of power. The theoretical belief was, that the same quantity of matter, being changed, would produce (if all the force could be utilised) the same amount of power; so that, theoretically, whether a pound of zinc was consumed, by burning it under a steam-engine, or the same quantity was employed to decompose water and then the gases were used, or in turning an electro-magnetic machine, provided nothing was lost, but the whole of the force was utilised, the results would, in every case, be identical as to the motive power obtained. Then there was the difficulty, not only of the cost of zinc, but also of other materials, sulphuric acid, for instance, which was the cheapest; all these went through a costly process before they were employed for these purposes. Thus a manufactured and consequently expensive matter was used instead of a crude material: unless therefore the power could be utilised to a far greater degree than was the case with the steam-engine, the difficulty was apparently insuperable. He did not think, that in the present forms of magnets, those powers could be utilised to anything like the required extent. The main advantage obtained in the electro-magnetic machine was, that when the machine ceased working, the expenditure of power ceased also, which was not the case with the steam-engine, and it was not until the power was put on again, that the consumption of material re-commenced, so that it marched *pro rata* with the work; this, however, was not sufficient to compensate for the disadvantage of having to use manufactured materials for the production of the force. Another point in favour of steam was, the smaller equivalent weight of the fuel: thus taking the equivalent of zinc as 32 and of nitric acid as 18, or indeed in practice more, say, 32 parts of zinc plus 26, or 27 parts of nitric acid, instead of 6 parts of carbon, this would give a consumption of from 50 to 60 parts of manufactured products, instead of 6 parts of crude product. If electricity could be practically obtained from coal and water, or from coal and air, the problem would be solved. It was known, that an electric current could be produced by the combustion of charcoal, or as Mr. Grove had shown, from flame: they were, however, far from the utilisation of such combustion, so as to convert its force entirely, or substantially, into an electric current, although an infinitesimal portion of that form of force could be obtained from the burning fuel; but although, at present, carbon could not be used, as the positive element of a battery, he saw no reason why it might not, at some future period, be so employed. Practically speaking, coal, in no form, had hitherto been made to serve, as the positive element of a battery. It had, indeed, at one time, occurred to him, that the difficulty might arise from carbon forming, with

two equivalents of oxygen, a compound which was not electrolytic, or practically soluble, and this notion was partly corroborated by the fact, that carbon acted better as the positive element, in an alkali, as potash, or soda, where the carbonic acid would be immediately absorbed, than in an acid solution; but the current even with an alkali was very feeble.

The great desideratum was, in his opinion, not so much the forms of the machine, as the improvement of the prime mover,—the battery,—or the economical mode of charging it. The forms of machine might be divided into three classes. First, there was the principle, which might be called the principle of suspension, or making and stopping the magnetism. Secondly, the principle of Ritchie, of inversion of polarity, and,—Thirdly, the deflecting principle,—*i. e.* the galvanometric principle—where the needle was deflected by a coil around it. This began with the maximum power, and by a succession of radial magnets would seem to keep it always afloat: but the power could not be concentrated in this case, as was done by means of a soft iron core in the other two forms. All the larger machines, he had seen, had been constructed upon the suspension, or inversion principle, the last being probably the best. The boat to which the Author of the Paper alluded was partly made under Mr. Grove's directions. The engine was worked upon the inversion principle—like the old toys of Ritchie, the poles being in succession inverted—of six radii acting between a large electro-magnet. In that boat he had travelled with two other persons, at a rate of three miles an hour, eight cells of a Grove's battery of 6 inches square being employed; but the expense put it out of the question, as a practical application. Thus, the important point, in relation to this subject, was to direct attention, rather to the source of power, than to the machine itself. At present, the only available use of this power must be confined to special purposes, where the danger of steam and the creation of vapour were sought to be avoided, for instance in small machines for cutlery-works, or where economy of space such as that required for chimneys, &c. was a great consideration. In special cases it might be useful, but the general application of electro-magnetism as a motive power was still, apparently, far distant.

Professor TYNDALL agreed with the conclusions of the last speaker, which were corroborated by the experience of the Author of the Paper, as to the disadvantage of employing zinc, in the production of mechanical force, in comparison with ordinary coal. With regard, however, to one of the experiments, on which Mr. Hunt's opinions were based, he would suggest, that the magnet employed was of a particular shape; and that by altering that shape, it would be possible to obtain either a speedier, or a slower diminution of the force with the distance than was shown in

Fig. 2; he felt sure that Mr. Hunt would not found a general conclusion on so special an experiment.

Another point referred to, was the alteration of the force of the current by the motion of the apparatus. That was no doubt due to the generation of induced currents, opposed in direction to the primary current, and therefore lessening its power. He would ask, whether it would not be possible to improve upon this, by some such arrangement as the following: supposing a primary current to be sent through a coil, with a bar of soft iron within it, and having its primary current weakened by an induced current; had it ever been proposed to wind round the electro-magnet a second coil of wire, not in contact with the battery, and to conduct the induced current formed in this wire, through a still longer wire, coiled round a second electro-magnet, in such a manner that the current should assist the primary-magnet? The equivalence between heat and mechanical force was of the greatest importance, both to the man of pure science and to the practical engineer, and he would suggest, that an experiment on a subject of such momentous practical bearing as this, ought to be well corroborated. It was a subject worthy the attention of engineers, and would confer a benefit, not only upon science in general, but upon their particular art, if the results already obtained, were confirmed by experiments of a delicacy commensurate with the importance and difficulty of the question.

Mr. C. COWPER said, although no practically useful result had hitherto been obtained, in the application of electricity to the production of motive power, it was advantageous to bring the subject before the Institution, even if only to obtain a record and summary of what had been accomplished, and thus to serve as a starting-point for future experimenters.

Having made several experiments on this subject, he desired to contribute his share to the general stock of information, and had therefore brought for the inspection of the members three different machines. The first was made by himself and his brother, Mr. E. A. Cowper, about the year 1838,—nearly twenty years ago. It consisted of a horse-shoe, or staple-formed, bar, $\frac{1}{2}$ inch square and 12 inches long, covered with 40 feet of copper wire about $\frac{1}{24}$ inch diameter. Over this there revolved a bar $\frac{1}{2}$ inch square and 4 inches long, covered with 20 feet of the same copper wire. At first this revolving bar was made of one piece of iron $\frac{1}{2}$ inch square; but, subsequently, he used a compound bar, made of six, or seven pieces of hoop iron riveted together, and which was found to be much superior to the solid bar. A bar was eventually built up of about fifty pieces of the thin sheet iron called "taggers," with still further advantage, as the compound bars retained much less magnetism, than the solid ones, and thus admitted of more rapid reversal of the polarity, and greater speed of rotation.

The construction of the commutator was found to be a matter of great importance: brass segments, with ivory between them, were tried, but the brass was oxidized by the sparks which were produced, and was very inefficient; it was therefore determined to avoid, as much as possible, the production of sparks, by causing the contact to be made with one segment before it was broken with the other; a commutator was therefore constructed, composed of two semicircles of silver, separated by a very small space, which was not filled with ivory, so that the rubbing wires came in contact with one segment, before leaving the other. The segments were also oiled, and by these means all the large sparks were avoided, although small ones were frequently produced, by the vibration of the wires, at high velocities.

With these improvements the machine was found to raise 3 lbs. one foot high, in a minute, being about $\frac{1}{10000}$ of a horse-power. The battery was one cell of Daniell's construction, 3 inches diameter and 6 inches high; the consumption of zinc was one ounce in eight hours. Allowing one shilling per pound as the cost of the zinc, including the acid and the sulphate of copper, less the value of the reduced copper, the cost of the power produced was about £4 per horse-power per hour. This machine was afterwards driven by a Grove's battery, and it then raised rather more than 5 lbs. one foot high, in a minute. With this arrangement, it was used to drive a bobbin and fly, at a lecture on cotton-spinning, given by his late father at the Royal Institution, in April, 1840.

A larger machine, constructed with several magnets, produced less power than this small machine. The commercial result of these experiments being so unsatisfactory, they were discontinued. The first machine frequently revolved at more than one thousand revolutions per minute, and the centre of action, of each pole of the revolving bar, then travelled about 900 feet per minute, or 15 feet per second, or $\frac{3}{16}$ inch in one-thousandth part of a second. As the chief part of the power was developed in a space of $\frac{3}{16}$ inch, over the poles of the fixed magnet, it followed, that the magnetism of the revolving bar must be reversed, or destroyed, in less than one-thousandth part of a second, to enable the machine to act effectively, at a speed of one thousand revolutions per minute. It appeared, therefore, that a greater velocity and useful effect might be obtained, if the moving magnet was made to pause, or to move very slowly, whilst the polarity was being reversed, or destroyed. A reciprocating motion, with a connecting rod and crank, was used by Mr. Davidson in 1842, and by many others subsequently, but the reciprocating motion was not adapted for high velocities, and the friction of the crank was excessive, as almost all the power was produced and applied to the crank, as it passed the centre.

Mr. Cowper succeeded, however, in combining the advantages of the crank motion with those of a rotary motion, by means of an eccentric-shaft machine, which he exhibited, constructed and tried in March and April, 1848. In this machine an iron shaft was employed having three eccentric portions, the central one being equal to the sum of the other two, and on the opposite side of the axis of the shaft. The shaft was, therefore, perfectly balanced, and was capable of revolving steadily, at high velocities. Two horse-shoe, or staple-formed electro-magnets, of the same dimensions as that employed in the first machine, were placed on opposite sides of the shaft. The poles of these magnets being flat, it would be obvious, that the eccentric portions of the shaft approached and receded from them, at the same velocities as if they were governed by a crank. The current of electricity was caused to traverse the wires of the two electro-magnets alternately, and the shaft was thus alternately attracted by them, and was caused to revolve with great rapidity. It was originally intended to add two other magnets, to act upon the central eccentric part of the shaft, but the results of the experiments were not sufficiently favourable to induce the completion of the machine in that manner. Various shafts were tried, from $\frac{1}{4}$ inch diameter to $1\frac{1}{8}$ inch diameter, and also a hollow shaft made of a piece of gas-pipe. The best result was obtained with a shaft of $\frac{9}{16}$ inch diameter, which was now used. The batteries employed were six Smee's batteries, charged with one volume of strong sulphuric acid, diluted with sixteen volumes of water. The active surface of the platinized silver of each battery was 25 square inches. The batteries were connected as a series, or the zinc of one battery to the silver of the next. The machine ran about 4,000 revolutions per minute, unloaded. With a load, the most effective velocity was from 1,800 to 2,600 revolutions per minute, and it then raised 21 lbs. one foot high in a minute, being $\frac{1}{1500}$ of a horse-power.

With a single Daniell's battery, $3\frac{3}{4}$ inches diameter and 20 inches high, the machine made one thousand and forty revolutions per minute, when raising 1 lb. one foot high per minute. It was allowed to work for one hour and a quarter, and at the end of that time it raised 1 lb. 6 oz. one foot per minute. The average was 1 lb. 3 oz., or during one hour and a quarter ·89 lbs. raised one foot. The zinc consumed was barely one-sixteenth of an ounce. Thus to obtain one horse-power there would have been $1\frac{1}{4}$ lb. of zinc consumed per minute, at a cost of about fifteen-pence, or £3. 15*s.* per horse-power per hour.

The first magnets employed in this machine were made of solid iron, $\frac{1}{2}$ inch square, but the above results were obtained from compound magnets, made of ten thicknesses of No. 18 charcoal plate iron, riveted together. The commutator employed in this ma-

chine was the same that had been used in the first machine. One pole, or electrode, of the battery, was connected to one end of the coil on each magnet; the other ends being connected respectively to the two segments of the commutator. The other pole, or electrode, of the battery, was connected to one of the bearings of the shaft. A brass spring, tipped with silver, was attached to the shaft, and the silver tip rubbed on the inside of the segments. It was at first made to rub on the outside of the segments, but it was thrown off by centrifugal force at high velocities, and when the spring was made strong enough to resist the centrifugal force, the machine would not run at low velocities.

In July 1848, Mr. Richard Roberts, of Manchester, showed him some very powerful electro-magnets, made by cutting parallel grooves in a square slab of iron, and winding a bundle of wires backwards and forwards in the grooves. Each rib thus acquired the opposite polarity to the adjoining ribs. It appeared, that circular magnets, constructed in a somewhat similar manner, would be well adapted for electro-magnetic engines. Accordingly, in November 1848, Mr. Cowper constructed the third engine exhibited, which might be called a "clutch engine." It consisted of two similar electro-magnets, the lower one being fixed, and the upper one revolving over it. Each magnet was in the form of a clutch, consisting of an iron disc 4 inches diameter and $\frac{1}{4}$ inch thick, from which twelve teeth projected $\frac{5}{8}$ inch, and had twelve equal spaces between them. The teeth extended from the circumference to within $\frac{7}{8}$ inch of the centre. Three bundles of copper ribbon were wound, alternately, in and out, round these teeth. In each bundle there were eight ribbons, $\frac{1}{8}$ inch wide and about $\frac{1}{45}$ inch thick. The ribbons were all connected, so as to form one continuous ribbon of 49 feet in length, and weighing 8 ounces. The iron of the lower magnet weighed 2 lbs. 2 oz. The upper one, with the iron shaft on which it was mounted and the silver commutator, weighed 2 lbs. $5\frac{3}{4}$ oz.

The commutator consisted of two clutch-formed silver rings, each of which had six teeth, which entered the spaces in the other ring, leaving a slight interval between them for insulation. The interior of the rings was filled with a resinous cement, to prevent the entrance of abraded particles of metal, which might form a connection, and destroy the insulation. The surface of the cement had, however, been carefully lowered, so that it might not come into contact with the silver tips of the wires which rubbed upon the commutator. The upper ring of the commutator was in contact with the iron shaft, to which was also attached one end of the ribbon, on the revolving magnet. The other end of the ribbon was connected, by an insulated wire, to the lower ring of the commutator. One of the rubbing wires was connected to one pole, or electrode, of the battery, while the other rubbing wire was con-

nected to one end of the ribbon, on the fixed magnet, the other end of which ribbon was connected to the other pole, or electrode, of the battery. The poles of the upper magnet were thus reversed twelve times, in each revolution, at the moment of their passing the poles of the lower magnet. In all the machines "lead" was given, and that "lead" was adjusted, until it was considered to produce the maximum effect, which diminished rapidly if too much "lead" was given.

This machine, with five Smee's batteries and one small Grove's battery, in a series, raised 8 lbs. 3 oz. one foot, per minute, making one hundred and five revolutions per minute; unloaded, it ran eight hundred and fifty revolutions per minute. The load was raised by a thread, winding on a boss on the shaft, and the machine had not sufficient time to get up to its full speed. It was, therefore, now fitted with Prony's brake, the lever, or arm, of which was $3\frac{3}{16}$ inches long, and described a circle of 2 feet in circumference. This lever was connected to the vertical arm of a bent lever, whose horizontal arm was of equal length, and carried a scale-pan. The power was thus equivalent to the weight in the scale-pan, raised 2 feet, by each revolution of the machine. The machine was tried in this manner very recently, and was found to run from two hundred and sixty to three hundred revolutions per minute, with a load of about 260 grains in the scale-pan, various loads being tried, with the brake adjusted to them. The maximum effect obtained was 21 lbs. one foot high in a minute. The battery consisted of two of Lemolt's batteries, connected as a series. The carbon element of each battery was $1\frac{3}{8}$ inch wide by $\frac{5}{8}$ inch thick, and immersed $4\frac{1}{4}$ inches in nitric acid, of a specific gravity of about 1·38, to which a little concentrated sulphuric acid had been added. The zinc cylinder was $2\frac{1}{2}$ inches diameter, and was immersed in very dilute sulphuric acid, containing sulphate of zinc, from previous experiments. The nitric acid had also been used in previous experiments.

This machine might probably be rendered more powerful, by making the iron teeth, or poles, of greater length, and winding round them a greater quantity of conducting wire, or ribbon. It would also be advantageous to make the teeth, or poles, of the revolving magnet of an assemblage of thin plates of iron, instead of making them solid.

Although there was not any proof of the fact, it did not appear improbable, that a chemical equivalent of zinc, consumed and oxidized, in driving a perfect electro-magnetic engine, would produce the same amount of power as an equivalent of coal, consumed and oxidized, in driving a perfect steam-engine. Zinc costs about sixty times as much per ton, and about three hundred times as much, per equivalent, as coal. If, therefore, there was only

realized one-tenth of the total effect from coal, and if the whole of the effect was realized from zinc, the cost of the power would still be thirty times that of steam power. This estimate was merely given as a suggestion, as there was not any proof of its correctness. In order to reduce the excessive cost of the power, it had repeatedly been proposed to sell the sulphate of zinc, or other products of the battery, for as much as the cost of the zinc and the other materials employed. The chief obstacle to this was, that purchasers on such terms were not to be found.

On the other hand, it had sometimes been admitted, that the cost of working these engines was much greater than the cost of obtaining the same power from steam, but that, owing to the lightness and compactness of electro-magnetic engines, they would be preferable, where lightness was of great importance, as in locomotive and marine engines. This proposition depended on the assumption, that they were lighter, for equal power, than steam-engines. This might be ascertained by calculating the velocity at which any of the engines could raise their own weight. Thus the clutch-engine, exhibited, might weigh, with the necessary batteries, about 15 lbs. This machine would, therefore, raise itself about 1 foot 5 inches per minute. The small locomotive exhibited by Mr. Davidson in the Egyptian Hall, in 1842, which he considered his best machine, would not have raised itself more than 8 inches per minute. A locomotive steam-engine of 30 tons weight and 100 H. P. would raise itself 50 feet per minute. In fact, the clutch engine, exhibited, weighed, with the batteries, about 10 tons per H. P. There was no doubt, that electro-magnetic engines of less weight, in proportion to power, might be made; but, as far as present experience went, there appeared to be no reason for supposing, that they could be made as light as steam-engines.

It had also been proposed to employ electro-magnetic engines, where only a small amount of power was required, as the tenth, or hundredth of a horse-power, and where the cost of the power was of less consequence. But even in such cases, a boy, or a man, turning a winch, would probably furnish the power at a cheaper rate.

Mr. Joule's experiments, as recorded in the "Philosophical Magazine,"[1] were valuable and interesting, but Mr. Cowper doubted whether any engine had ever been made to give a useful effect of 54 per cent. of the theoretical power developed, or been worked with so little as 4 lbs. of zinc per horse-power per hour. His own small engines consumed 70 lbs. or 80 lbs. per horse-power per hour by friction break, or weight lifted, and he thought Mr. Joule's would have consumed half that quantity, if tried in

[1] "Phil. Mag." (3rd series) vol. xxviii.

the same way. In Mr. Joule's experiments three batteries in a series were used, and each was allowed to consume the theoretical equivalent of zinc. This at once reduced the useful effect from 54 per cent. to 18 per cent. The power was estimated by allowing the engine to run without any load, the speed and the consumption of zinc being noted. The batteries were then disconnected, and the engine driven by a weight on a cord going round the shaft, and this weight was increased, until the engine ran at the same speed as before. The rate of descent of the weight having been found, and that multiplied by the weight, the result was called the power developed. But this was not useful effect, as the whole of it was consumed in friction and resistance of the air, &c., so that the useful effect at that speed was nil. If a load had been put upon the engine, its speed would have been reduced, and the consumption of zinc increased, so that the useful effect was probably not more than 6 per cent. of the theoretical maximum.

Mr. SMEE agreed with, and had constantly and earnestly, in his various works, during many years, enforced, the doctrine advanced by the Author of the Paper, with regard to the cause of failure of electro-magnetic machines, in an economic point of view. In all forces it was essential to regard the primary change of matter, or the new attraction set up, to produce the phenomena which were manifested. In the steam-engine, the power was derived from the attraction which was exerted between the coals and the oxygen of the atmosphere. In that case, the oxygen cost nothing, and coals were obtained at a cheap rate. In a battery, the attraction between the zinc and the oxygen of the water was the source of the power. Although zinc was dear, and the water required the addition of sulphuric acid, the battery had one great advantage, because, in a well-constructed instrument, the initial change which occurred to produce the power could all be used, within a very small per centage of waste, for numerous purposes. He had ascertained this fact in his own battery, whilst making the types by which the Bank of England notes were printed. Although it had been in use for three weeks, without re-amalgamation, or changing, it did its work, within a small fraction, equivalent to the change which took place in the battery; and he found that a well-arranged instrument would act for many months without alteration. He considered that the most perfect results, with regard to the primary changes, were obtained with the voltaic battery; but when, in comparing the equivalents of zinc with the equivalents of coal—the former being 32, and the latter only, as hydrogen and carbon, 1 and 6—there was a difference greatly in favour of coal, as a source of power, and, moreover, carbon entered into two attractions with oxygen to form carbonic acid. Then there was the great difference of cost with regard to zinc; and if other metals were em-

ployed, to generate power in the battery, in the majority of instances the expense would be greater. He had tried tin, but it was more expensive; iron, although cheaper, had also been employed, but not advantageously; and it would be found that, unless the products of the new attraction were commercially utilized metals, all metals having in the first instance to be manufactured with hydrocarbon, or coal, were much dearer than when the coals were used direct. He had tried extensively the use of hydrocarbons for a positive pole, but they were not practically efficient. He thought, with regard to the voltaic combinations, that the hydrogen which was allowed to escape might be utilised advantageously for some purposes. With reference to the sulphate of zinc, which was the compound formed by the new attraction in his battery, although it was extensively used in surgery, and theoretically should be sold at a profit, as a manufactured article, yet he had found it cheaper to throw away that produce of the batteries, than to evaporate the solution into a marketable material. He had taken great pains to find a market for the sulphate of zinc formed in his batteries, but hitherto without success. The sulphate of zinc required a certain quantity of water to dissolve it, whilst the new matters formed in the burning of a furnace were sent out into the atmosphere. Hence there was no such thing as a small productive battery. The trough of the battery must be of sufficient size to dissolve a certain amount of zinc, which was a great disadvantage as against the battery, in large operations. With regard to the operation of magnetic machines, he had found, in common with all who had experimented upon the subject, that the cost, from the above causes, would be enormous for heavy work; and he thought the true theory of the cost was to be sought from the equivalent number of the matter changed, and the expense of the materials which entered into the new attraction. Although motive power could not at present be produced at the same expense, on a large scale, by the agency of the battery, as it could be by coal, still they were enabled readily to apply the power at any distance from its source, and the achievements of the electric telegraph might be regarded as an application of motive power by electricity, which was by no means to be despised. From his experiments, he believed that in animals force was applied, at a distance from the brain, by electrical agency; and whenever it was desirable to regulate, or to apply force at a distance, electro-motive power might now be very advantageously employed.

Mr. PETRIE said, he had devoted much time and thought to the action of the permanent magnet, and had arrived at identical results with those described by the Author and by the previous speakers. The system could only be practically applied at enormous cost. The results of the relative value of the power pro-

duced from zinc in a battery and the amount of zinc consumed per horse-power produced, agreed with his own observations. His particular object, in experimenting, was to obviate the difficulty of the short distances over which the power acted, in the case of ordinary electro-magnets. The advantage of the deflective power, giving action over a distance of 12 inches, in the place of only a fraction of an inch, was of great benefit. He obtained a permanent action equal to raising about 18 lbs., but that was reduced, directly it was attempted to attain any velocity. All the difficulties described with regard to the form of the magnet, &c., were minor considerations. The grand point appeared to be, the mode of dealing with the induced current, which was the secret of the great reduction of force, whenever motion commenced; and the induced current increased in proportion to the rate of motion, and up to the present time that difficulty appeared to be insurmountable. Many remedies had been suggested, but most of them appeared to be of the same nature as the attempts to produce perpetual motion, by mechanical means. Induced currents were the necessary effects of the generation of the power, and it was by virtue of those induced currents, that they were prevented from obtaining infinite power from batteries of finite dimensions. If it was not for these currents, it would be possible to work at any velocity. Not being aware of the real effect of the induced currents, when he commenced his experiments, he fancied that he was on the eve of obtaining infinite power by finite means; but he soon discovered the mistake, and became aware that he was attempting to obtain little short of perpetual motion. It seemed to be a loss of time to attempt to deal with this induced current; therefore it was necessary to search in some other direction, to improve the power, in order to bring it into practical working condition.

The main idea, which had been so well noticed, was the comparative value of the forces produced from zinc and from carbon, the results being decidedly against the former. The relative affinities of atoms of carbon and atoms of zinc, for oxygen, must be borne in mind, as they were so different as to preclude the economical use of zinc, for the production of power; hence arose the idea of obtaining power from carbon, by first producing electricity, instead of heat from oxidation. As to the nitric acid used in the batteries, it was only necessary to expose the residuum to the action of air and moisture, and it would be reconverted into nitric acid; or the same result might be effected by filtration through finely-divided matter, such as pounded coke, while exposing it to the action of the atmospheric air. Thus an important item of expense in a battery might be reduced.

Mr. G. P. BIDDER, V. P., said, the Paper was one of great interest; the Author had treated the question very ably, and had

brought it to a point which admitted of its being examined, as to the commercial results; but, at the same time, he had shown, that there had, hitherto, been a lamentable waste of mechanical ingenuity, in attempting to bring electro-magnetism into use on a large scale. The several created forces now used were—manual power, produced by animal and vegetable food; horse power, produced by oats, grass, and hay; electro-magnetism, resulting from zinc and acids, and steam-power, produced by the action of coal. Assuming, that a man could not be kept in good working condition for less than two shillings per day, nor a horse for less than two shillings per day, on comparing the cost of different means of producing power, it would be seen that, for every shilling expended, there might be raised by

Manual power .	600,000 lbs.	one foot high per day.
Horse „ .	3,600,000 lbs.	ditto.
Steam „ .	56,000,000 lbs.	ditto.
Electro-magnetism .	900,000 lbs.	ditto.

Mr. R. HUNT, adverting to the remarks of the previous speakers, as to the action of magnetic forces through space, said it had been asked if the electro-magnets of the horse-shoe form had shorter arms than those represented in Fig. 2, and whether the diminution of force, through space, would not be different from the rate of diminution observed with such a magnet as that represented. Now, the numerical results given in Fig. 2 were the mean average results actually obtained by experiments with magnets of various forms—some having long and others short arms, and especially from one, as contrived by Mr. Joule, which had exceedingly short arms, and was made of a series of plates of iron, each plate covered with clothed wire, and then bound together. The results there represented, and those (on Fig. 7) of Hjörth's engine, were obtained under the best possible conditions, giving the mean average of a great number of experiments. With regard to the force of the currents, with the magnet at rest and in motion, it had been suggested, that the induced current was the cause of the falling off of the force, when the magnet was in motion. As had been remarked, this might, in some degree, be remedied by winding round the magnet a closed coil of wire, not connected with the battery, the induced electricity in which might be employed to produce magnetism in another bar of iron, which magnetism it was argued could be employed. This plan was tried by Hjörth; but, from the difficulty he experienced, in dealing with this current, when the magnet was in motion, he was induced to abandon it. Mr. Hunt had also tried it, and had found that the power from the second magnet, thus created, was of very inferior moment, in any form of machine which he could devise,

and was not available for any practical use. He had recently received a communication from Mr. Joule, and as the opinions of so eminent an authority might be interesting, he would briefly quote them :—

Mr. Joule said, "It was to be regretted that, in France, the delusion, as to the possibility of electro-magnetic engines superseding steam, still prevailed. Fifteen years ago, it had been proved, experimentally, that the heat evolved by any voltaic circuit, in which an engine was not included, was exactly that due to the chemical actions taking place, the conducting wire merely presenting the means of evolving the heat in any given locality, instead of its being all evolved where the chemical action took place. This discovery, which had been erroneously attributed to M. Favre, whose experiments were only three years' old, was followed up by the discovery, that if an electro-magnetic engine was placed in the voltaic circuit, the heat evolved, corresponding to a certain chemical action, was diminished, the heat which disappeared, being converted into the mechanical force given out by the engine. The greater the quantity of heat which disappeared from the voltaic circuit, relatively to the heat due to the chemical actions, the more perfect would be the economy of the electro-magnetic engine; and as it was possible to make the engine work, so as to reduce the intensity of the current to a very small fraction of its strength, when the engine was not working, nearly the whole of the heat due to the chemical actions of the battery might be evolved as work. Supposing all of it were converted into work, there would result 145 foot lbs. for each grain of zinc consumed in a Daniell's battery. It was the weakness of the chemical actions of a voltaic pile, as compared with that of the combustion of coal, and the relative cost of zinc and coal, which decided so completely in favour of the steam-engine. As regarded the strength of the chemical actions, one grain of zinc, consumed in a Daniell's battery, gave out heat equivalent to 145 foot lbs.; but one grain of coal, burnt in air, produced heat equivalent to 1,261 foot lbs., or nine times as much; so that if a steam-engine was so bad as to convert only one-ninth part as much heat as the electro-magnetic engine, the two would still be on a par. As to expense, it was obviously impossible that the cost of coal could ever become more than a minute fraction of that of zinc, to say nothing of that of other necessary materials."

It has been asserted, that the results arrived at by Joule, had not been confirmed by other experimentalists. This was not the case, as similar researches had been undertaken by Professor W. Thomson, and Dr. Scoresby had worked with Joule on this problem; it had also engaged the attention of Professor Bunsen, of Marburg, and, more recently, of M. Favre, who had arrived

at the same conclusions, as those recorded by Joule, and the general testimony was entirely in favour of the views which Joule entertained.

Mr. T. ALLAN said, it would appear that those who had hitherto directed their attention to the subject of electro-motive power, had commenced at the wrong end. They seemed to consider, that the whole question resolved itself into producing a certain amount of electricity at a given cost. The chemical question, in fact, was considered, instead of the mechanical application of a given force. Magnetic force died rapidly away through but a short space. If the geometrical curve of the dynamic force of magnetic attraction was drawn, and was divided into ten parts, it would be found, that if the tenth nearest the magnet gave a mean power equal to 1,000 lbs., the mean force of the tenth part furthest from the magnet would only be 3 lbs., though the same amount of electricity would be used in the one case as in the other. Taking the mean of the whole attraction of a magnet, only a small power was obtained, but through so short a distance as to be mechanically unavailable. In Jacobi's engine, in which the rotary principle was adopted, the minimum portion of the magnetic attraction only was applied, giving but a small power, with a large consumption of electricity. In Mr. Allan's electro-magnetic engine, in which a different form of magnet, with four, six, or eight poles placed upon a plate, had been adopted, it had been endeavoured, by a direct action, to apply the maximum portion, only, of the dynamic force, and this, by a succession of magnets, was successively and continuously brought into action, giving a comparatively large power, with a small consumption of electricity, and producing, in a machine, a continuous motion analogous to the overshot water-wheel.

It was to be hoped that, though apparently impracticable now, in process of time electricity might be applied as a motive power; for when it was considered, what had taken place with regard to electricity,—how, in the first instance, it had been obtained from friction upon amber, or glass—was then developed by chemical action from metals—and was subsequently manifested by the influence of heat on solid bodies, as shown in the form to which the name of thermo-electricity had been given,—it was felt, that a series of careful researches into the undeveloped secrets of this marvellous element, might result in a means of producing the power, which would render it as economical and advantageous as the heat which was now obtained so easily. It was only a few years since Sir Humphry Davy was compelled to employ a thousand pairs of zinc and copper-plates to do the work which twelve of the same agents would perform, in a modern battery.

Mr. SMEE said, with respect to the question of how near a

battery, acting over a considerable time, would do the work, that was due to the attraction going on in that battery, he found, from his experiments upon the plates for the production of the Bank of England notes, that the waste of zinc in a single cell of the battery during eighteen days was 19,414 grains, and that in the decomposition cell the positive poles lost 19,139 grains. The difference between these two would be the real difference, or loss of power, between the work performed and the new attraction set up in the battery, which he apprehended was for the work done in relation to the matter changed or burnt, nearer than could be obtained by any other means. This was accomplished in one of the batteries devised by him and ordinarily called "Smee's Battery." But with a "Daniell" battery another change was going on; the hydrogen was decomposing the sulphate of copper, and the equivalent of power could not be obtained at less than double the expenditure of simply employing zinc. Then again with a "Grove" battery, the nitric acid was decomposed by the hydrogen, and was even more costly than the "Daniell" battery. The nitric acid was destroyed, and the change that occurred was three, or four times as much as when zinc alone was dissolved. He was not aware, that either Daniell's, or Grove's batteries had ever been employed for any lengthened period. It appeared to him, that batteries would effect that, which he believed, no mechanical force would alone effect. First, the power could be used at any distance; and secondly, the battery, when once charged, would continue to work, over a long period of time, without further attention. The fall of the time-ball at Deal, by which the chronometers of the mercantile navy were regulated, was *de facto* an application of motive power, produced by one of his batteries at the Greenwich Observatory. The same motive power was employed for regulating the time at the Post-Office, the Great Western Railway Station, and other places, and the point in which this power exceeded all others was the extreme distance at which it could be applied. Theoretically, battery power ought to be generated at a profit. The sulphate of zinc produced in these batteries was a product of value in the arts, and should find a ready market; it ought to be sold at a profit to the manufacturer, and by that means electricians should obtain their power almost without cost. At present, no profit had been derived from the sale of the sulphate of zinc, as the manufacturers preferred preparing it themselves, rather than incur the expense of sending carts for the solution made by the battery. The residuum was produced in large quantities in the preparation of the plates for the Ordnance Survey, where his batteries were employed on a large scale; the sulphate of zinc so obtained had been sold, and had become a matter of consideration in a commercial point of view. The great desideratum was to obtain

electro-motive power, not only without cost, but at an actual profit. It had been attempted, as a commercial speculation, but hitherto, he believed, without success. He could not agree that the theory of the battery was not a fundamental question, in considering the question of electro-magnetic power. In the production of all forces there must be an atomic change. The cost of that change alone precluded the use of zinc instead of coal, in producing gas. Nearly twenty years ago he attempted to use the gas from one of his large batteries, for the purpose of lighting his own house; there was not any difficulty in arranging a small apparatus for the purpose, but he estimated that the gas so obtained, instead of costing six, or seven shillings, per thousand feet, which was the price of coal gas at that time, would cost £7 per thousand feet. He believed zinc at the present time was the best and most economical material for obtaining battery power, even when all the products were thrown away; but, at the same time, the power thus obtained was nearly a thousand times dearer than if coal was employed. In using the term coal, he meant it in the more extended term of hydro-carbons generally, as he had attempted to employ them. He had obtained a certain amount of voltaic power when sugar, oxalic acid, and various other materials, were used as positive poles, but it was very insignificant, as compared with the power obtained from zinc; and if a substantial amount of power was required, enduring week after week and month after month, and even for a whole year, without deviation—as, for instance, for an electric clock—no other substance was at present known, which would produce effective power so well as zinc. He was, therefore, sorry to hear it asserted, that the battery power might be neglected, in the consideration of electro-motive power, as he was satisfied, on the contrary, that it was the primary object to which attention should be devoted. With regard to the mode of employing the magnet, he believed that human ingenuity was by no means exhausted, as to the best form of applying this power. At present it was used for long periods of time and at considerable distances, and in that respect was, perhaps, superior to any other mechanical power for small effects; it was similar to the operation upon the nervous system on animal nature, where the power was transmitted from the brain to the extremities, to impart motion. Electrical power could be used at immense distances from where it was produced, as, for instance, in working electrical clocks, detaching the time-ball, &c., to which he had previously alluded. These were the legitimate uses of electric power, and in this direction science would yet produce more marked results, and there was reason to hope that electrical power might still be obtained more economically, and be used more extensively.

Mr. R. HUNT still hoped, that in process of time electricity

might be applied as a motive power. The object he had in view in bringing forward the Paper, was to endeavour to show that, with the present voltaic battery and appliances, it was absolutely impossible to employ electro-magnetism as a motive agent with any practical advantage. He could not agree with the remark, that they had began at the wrong end. Before a steam-engine could be driven, the construction of the boiler and of the furnace must be considered; so likewise, as the battery was the primary source of power, it was essential to establish that form and combination which produced the power most effectively and economically.

It should be observed, with reference to the convertibility of chemical into mechanical forces, that in the oxidation of the zinc in a voltaic battery a certain amount of power was developed, in the shape of electricity; so, in like manner, a certain amount of power was obtained in the shape of heat from the oxidation of carbon in the furnace, to be employed in vapourizing water, and the expansive powers of that vapour were used in driving machinery. Now, although in the battery another form of force was developed as electricity, it appeared to him that electricity might be employed in some way analogous to the method in which heat was now employed. Electricity was now operated with, having particular reference only to its attracting and repelling powers, and there appeared to be considerable difficulties in its application, especially the small distance through which the force acted, and the rapid ratio of its decline in power. The nearest mechanical arrangement which might be considered, in relation to the steam-engine, was in Hjörth's machine, which consisted of an electro-magnetic cylinder, into which, and from which, there moved an electro-magnetic piston. When first the action commenced, drawing the piston into the cylinder, the mechanical force continually increased, as the piston passed towards and partially into that cylinder; but when it came to the repelling force, to drive the piston back again, there was a continual diminution of mechanical force from the first commencement of motion, and in that respect the difference, as compared to the steam-engine, was manifested.

Mr. GRAVATT remarked, that in decomposing water hydrogen and oxygen were produced, and being both elastic gases, the process might, when these gases were generated under pressure and made to raise a piston, to some extent, be compared to the production of steam, and this was the nearest approach to the condition of the steam in a boiler. Of course the gases might be afterwards burnt together, and in this manner he had worked a miniature experimental engine: the only question was the expense; in fact, in the one case zinc, and in the other case coal, were respectively the fuels used to obtain power.

Mr. E. HIGHTON thought, that the subject under discussion ought to be divided into two distinct parts—first, the mode of producing electricity, and second, the apparatus to which such electricity was to be applied. If possible, the natural products to be found in the earth ought, for the sake of economy, to be employed in both cases, instead of products manufactured at considerable cost. Hitherto, electro-magnetic engines had not been constructed in accordance with a power varying inversely as the square of the distance, for which he suggested certain remedies. He also recommended, that a modification of the waves of contraction in muscular fibre should be adopted in electro-magnetic engines, and stated that there were certain peculiarities common both to muscular fibre and to the electro-magnet, particularly as regarded sound, which was developed in both, on the production of a pulling power; and each was a substitute for nervous energy. Electricity could be used either directly, by means of the electro-magnet, or indirectly, by the explosion of gases. Heat, electricity, electro-magnetism, magnetism, and pulling power were all only different manifestations of one and the same force, and each was convertible into any other. He then analysed the mechanical effect of a flash of lightning, and showed that, in a certain instance, the power developed through 50 feet was equal to a 12,220 H.P. engine, and that the initial explosive power was equal to a pressure of three hundred millions of tons. The desirability of obtaining a motive power requiring less weight per H.P. than the steam-engine was unquestioned, and he referred, incidentally, to some experiments which had been tried, at different times, with this object in view. In this way it had been ascertained, that the motive power derivable from the chalk formation near London, would cost four times more than that obtained from coal. The power to be derived by the production of the vapour of a volatile spirit by the condensation of steam—from the explosion of a mixture of hydrogen and oxygen by electricity—from the condensation of the vapour of a highly-volatile spirit by ice—and by a certain quantity of solid hydrogen and oxygen, by means of the steam-engine and by means of the muscle of the horse, were successively described; and it was stated, that the latter gave out nearly ten times as much power as the most perfect present arrangement of the steam-engine in Cornwall.

Mr. R. STEPHENSON, M.P.,—President,—in closing the discussion, remarked, that there could be no doubt, from what had been said, that the application of voltaic electricity, in whatever shape it might be developed, was entirely out of the question, commercially speaking. Without, however, considering the subject in that point of view, the mechanical application seemed to involve almost insuperable difficulties. The power exhibited by electro-

magnetism, though very great, extended through so small a space as to be practically useless. A powerful magnet might be compared, for the sake of illustration, to a steam-engine with an enormous piston, but with an exceedingly short stroke. Such an arrangement was well known to be very undesirable.

In the mechanical application of power, velocity, or in other words, the space passed over, was made as large as possible, and in proportion as this was accomplished had the efficiency of the machine been extended. Now this was precisely the difficulty under which the application of magnetism laboured, the space through which it could be made to extend being so exceedingly small. The example of letting fall the time-ball at Deal, and in other places, could not be quoted as an exertion of power; the abstract fact of the falling of the ball was evident, but the apparatus by which the ball was set free was of a very delicate nature, so that a very slight impulse sufficed. If the ball was raised by electric action it might be adduced as an exertion of power.

With respect to the very imperfect use of heat in the ordinary steam-engine, some reasonable doubt might be entertained as to the correctness of the methods employed, to arrive at the unit of heat now employed by scientific men; for when it was stated, that the ordinary duty obtained by a good steam-engine was about $\frac{1}{10}$th of what the quantity of heat, actually generated by the consumption of a given weight of carbon, was really capable of performing, some doubts naturally suggested themselves, as to the correctness of the mode by which such a result was arrived at; for it appeared impossible to conceive where such an enormous loss could take place.

This part of the subject would seem to require further investigation, and it might be suggested, that the power necessary to destroy molecular attraction might not be comparable with the ordinary mode of developing power, by imparting heat to elastic vapours. The one was an enormous force exerted over an infinitely small space, and the other, on the contrary, was a limited power exerted over a very large space. This view would seem to be corroborated, or might derive illustration, from considering the well-known mechanical difficulty of comparing a given pressure at rest, and another pressure with a given velocity. It was well known, in fact, that they were not comparable.

Calculating Machine.

The attention of the Members was especially directed to a small volume presented by Messrs. Scheutz, of Stockholm, through Mr. Gravatt, (M. Inst. C.E.,) entitled "Specimens of Tables, calculated, stereo-moulded, and printed by Machinery." The book, which was, with excellent feeling, dedicated to Mr. Babbage, in recognition of the generous assistance he had afforded to the ingenious labourers in a similar field to that in which he had so long toiled, was preceded by a short memoir, describing the progress of the construction of the machine, under the most discouraging circumstances,—the ultimate success obtained,—the introduction of the machine, in this country, through Count Sparre, to Messrs. Bryan Donkin & Co., where Mr. Gravatt became interested in it, and placed it before the Royal Society, and the Institution of Civil Engineers,—its success at the great Exhibition at Paris in 1855, where it obtained a gold medal,—and finally its acquisition, through Professor B. A. Gould, for the Dudley Observatory, at Albany, U.S. America, as a gift to that establishment from Mr. John F. Rathbone, an enlightened and public-spirited merchant of that city.

The construction was briefly described, and it was shown that, at the average rate of working, one hundred and twenty lines per hour of arguments and results were calculated and stereotyped ready for the press. On trial, it was found, that the machine would calculate and stereotype, without chance of error, two pages and a half of figures, in the same time that a skilful compositor would take merely to set up the types for one single page.

There was also given an abstract of Mr. Gravatt's description of his manner of considering and working the machine, and then followed tables of logarithms of numbers from 1 to 10,000; and various examples of calculations performed with unerring accuracy. The remarkable and unique feature of the book itself was, that the tables and calculations were all printed from stereotyped plates produced directly from the machine, and without the use of any moveable type.

The special thanks of the meeting were given to Messrs. Scheutz for the present, and to Mr. Gravatt for taking charge of this interesting addition to the Library.

May 5, 1857.

ROBERT STEPHENSON, M.P., President, in the Chair.

The following Candidates were balloted for, and duly elected:—GEORGE BUCHANAN, JOHN WILLIAM BYRNE, and JAMES HENDERSON, as Associates.

No. 971.—"On the employment of Rubble Béton, or Concrete, in Works of Engineering and Architecture."[1] By GEORGE RENNIE, M. Inst. C.E., F.R.S.

THE employment of rubble and concrete in public works is coeval with the earliest periods of antiquity, and according to the best and most ancient authorities, those materials were used in all the cities and public buildings of Egypt, Assyria, Etruria, Greece, Rome, China, India, and South America, long before the Christian era. The pyramids of Egypt; the walls of Babylon and Nineveh; the Pelasgian, or Cyclopean walls, of Tyre, Cora, Nubia, Syria, &c.; the Etruscan cities of Alatrium, Ferentium, Herculaneum, and Pompeii; the cities of Argos and Mycene; the Acropolis and fortifications of Athens; the great wall of China; the Topes, or Buddhist towers and temples of India; the temples of Cholula and Cusco, in Mexico; and the ruins of the cities discovered in Peru, by Stephens and Catherwood, are instances of their use on an immense scale.

It is from Italy, however, that is derived the more intimate knowledge of the practice of the art of building in rubble, and that country was more particularly calculated to transmit the knowledge, as it was there (according to Pausanias) that the Etruscans are said to have built Licosura and Tirentium, the first cities recorded, about thirteen centuries before the Christian era. Many great works in civil engineering were afterwards undertaken in Italy, such as the drainage of the valleys of the Arno and of the Tiber, and of the lakes of Albano and Copais: the arches and tunnels by which those drainages were effected, exhibit evidence of the general use of concrete, and in the remains are specimens of the arch in all its stages of progress—from the stone lintels, such as exist in the gateways of the ancient cities of Cora, Cortona and Signia, and the overlapping stone systems of Missolonghi and Mycene, the

[1] The discussion upon this Paper extended over a portion of two evenings, but an abstract of the whole is given consecutively.

treasury of Atreus and the tomb of Galeassi,[1] down to the radiated and equilibrated arches of Delos and Cora, showing their knowledge of the principles of the arch. The introduction of the arch into Rome, by the Etruscans, led to its adoption in all the public buildings of that city. With the exception of the Cloacæ, and the vaults which served for the subsidiary drainage of the valley of the Tiber, the remains of the Etruscan buildings in Rome are few. The long period of the Roman Republic did little for the building art, and it was not until the time of Porteus Cato[2] (the most ancient of all the Roman writers) and Vitruvius[3] (who wrote two centuries after him) that the Romans had any knowledge of the use of mortar in buildings.

The use of rubble was greatly aided by the existence of extensive beds of volcanic deposits, which lay in the vicinity of Naples and Rome, and which Vitruvius describes minutely, thus translated in Gwilt's edition[4]: "That powder is procured, which is found in the country between Cumæ and the promontory of Minerva, and is mixed with the water in the proportion of two parts thereof to one of lime. Then, in the place selected, dams are formed in the water, of oaken piles tied together with chain pieces, which are driven into the bottom. Between the ranges of the piles, below the level of the water, the bay is dug out and levelled, and the work carried up with stones and mortar, compounded as above directed, till the wall fills the vacant space of the dam. If, however, from the violence of the waves and open sea the dams cannot be kept together, then on the edge of the main land, a foun-

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[1] *Vide* vol. iv., "Architettura Antica, P. H. Carlo Luigi Canina."
This writer considers the invention of rubble walls to be due to the Cyclopeans, and the most ancient city round which they were built, was called Licosura, situated on Monte Licio, 1550 years B. C. About 150 years after this Preto invited the Cyclopeans to build the walls. Preto also, about the year 1380 B.C., applied a similar system of building, with angular stones, and the interstices filled in with rubble, to Tirentium, an ancient city of Argolide. Pausanias (lib. x. cap. 5) says, that the construction of the early temples was effected in the same manner. The Etruscans applied the same mode of building to the cities of Corte, Fiesola, Volterra, Latium, Cora, Norma, Preneste, and others. Pliny and Vitruvius attributed the invention of mortar and concrete to Doseo, son of Celo, who assimilated it to the mode adopted by swallows, in building their nests (con cui le Rondini facevano il nido).

[2] *Vide* "De re Rustica," cap. 15. His precept was two measures of sand to one of lime.

[3] *Vide* Vitruvius "De Architectura," Book II., chap. 6, in which he treats "de Pulvere Puteolano:" "Est etiam genus pulveris, quod efficit naturaliter res admirandas. Nascitur in regionibus Baianis et in agris municipiorum, quæ sunt circa Vesuvium montem, quod commixtum cum calce et cæmento, non modo ceteris ædificiis præstat firmitates, sed etiam moles quæ construuntur in mari, sub aquâ solidescunt." Also Canina's "Etruria Antiqua."

[4] *Vide* "The Architecture of Marcus Vitruvius Pollio," in ten books. Translated from the Latin by J. Gwilt. 8vo. London, 1826. Book V., chap. xii., p. 157, "Of Harbours and other Buildings in Water."

dation for a wall is constructed of the greatest possible strength: this foundation is laid horizontally, throughout rather less than half its length; the remainder, which is towards the shore, is made to overhang. Then, on the side towards the water, and on the flanks round the foundation, margins, projecting a foot and a-half, and brought up to the level already mentioned. The overhanging part is filled up underneath with sand, brought up level with the foundation. On the level bed thus prepared, as large a pier as possible is built, which remains for at least two months to set. The margin which incloses the sand is then removed, and the sand being washed away by the action of the waves causes the fall of the mass into the sea, and by a repetition of this expedient the work may be carried forward into the sea."

Vitruvius afterwards goes on to say, that the wall is then to be raised with square stones, the joints of which are to be as long as possible, in order that the middle stones may be well tied. The inside of the wall is then filled in with rubble and masonry, and on this even a tower may be erected.[1]

Rubble was used in all the public buildings in Rome, and throughout the Roman empire, and the occurrence of rubble and concreted work, in almost all the masses, walls, domes, and cylindrical vaults, which still exist among the ruins of the palaces, baths, theatres, aqueducts, and cisterns in that city, attest its durability. The Coliseum, the Baths of Caracalla and Dioclesian, the Temples of Peace and Minerva Medica, and the Theatre of Marcellus; the Tomb of Cecilia Metalla, and most of the tombs which line the Appian Way as far as Albano; the foundation of the Appian Way itself, and of all the great roadways of the empire; the moles and harbours which surrounded the coast of Italy, such as Brundusium, Ancona, Rimini, Naples, Niceta, Ischia, Procida, Baiæa, Terracina, Anzium, Ostia, and Civita Vecchia (most of which the Author has visited and examined), are so many instances of the application of rubble and cement; and the remains of large fallen masses of domes, of upwards of 100 feet span, and cylindrical vaults of upwards of 80 feet span, still existing in many of the Roman buildings, are proofs of the excellence of rubble united with brick and pozzuolano cement. The arches of the Roman bridges were usually constructed with large voussoirs of masonry, covered over and between the haunches with rubble, from the period of the radiated arches in rings of the Cloacean sewers, down to the latest bridges over the Tiber. Throughout the Roman colonies of France, Spain, and Carthage, the same system was practised. Many examples exist among the aqueducts,

[1] The mode of launching a mole is described in Virgil's "Æneid," Lib. iii., ver. 710, *et seq.*

amphitheatres, and bridges of France, at Arles, Autun, Lyons, Nismes, Trèves, &c.; in Spain at Alcantara, Seguntum, and Terragond; and in the North of Africa at Tunis, Constantina, Philipeville, and Stora. In short, from the termination of the Roman empire, to the establishment of the Christian era, under Theodosius and Constantine, — when the style of architecture changed from the debased Roman to the Byzantine and Romanesque,—from the Church of St. Sophia, at Constantinople, and its contemporaries, the five Basilicæ at Rome, built by Constantine himself, to the commencement of the pointed style by Theodoric, and to the general continuation of this style, usually termed Gothic, throughout Christian Europe, the same principle of constructing the foundations, walls, and fillings-in between the ribs of groined arches, with rubble and masonry, continued to prevail, and the numerous ecclesiastical and feudal edifices which are scattered throughout Europe attest the universality of the practice.

The science of construction was reduced to its simplest forms among the Greeks, as they relied on the magnitude and excellence of the materials with which they had to deal. It was, in fact, a question of proportion and harmony, to produce the required effect. Not so with the Romans. They were indebted to the constructive skill of the Etruscans for the introduction of the arch, and the use they made of it enabled them to vault and dome large edifices, and build bridges over rivers, to an extent never practised by the Greeks. The vaultings of the Baths of Caracalla, Nero, and Titus, and the various domes and arches of the Pantheon, the Coliseum, the Temples of Peace and Minerva Medica, and other edifices, and the bridges over the Tiber, at Rome, and at Narni and Vieille Brioude, in Italy and France, prove that they were capable of equalling any works of a similar kind in modern times.

The earliest account, after Vitruvius, of the system of building with concrete, is given by Philibert Delorme in his work on Architecture, "Un Traité complete de l'Art de Bâtir," in which the principles laid down by Vitruvius are detailed and amplified (Chapter XI.). After considering the nature of the foundation, whether required for an edifice pier, a bridge over a river, or a marsh, he gives directions how to proceed with the building.

Alberti, Scamozzi, Palladio and Barbaro, of the Italian school of architects, contented themselves with following up the principles of Vitruvius, as did the followers of Philibert Delorme, of the French school. In 1748, one of the jetties at Toulon was made entirely of béton, under M. de Montville; and in 1774 the first great dry dock (basin de radoub) at Toulon, by Groignard, was

constructed with similar materials; both of these were considered successful applications of béton. From the year 1776 to 1800, great progress was made in the application of rubble, or bèton, to engineering works in France. In 1789, experiments were made on an extensive scale by Le Père, directed by M. De Cessart, on the summit of one of the cones of the breakwater of Cherbourg, of which he was Chief Engineer; also on different compounds of béton, with the admixture of pozzuolano. The great cost of the latter material in France, at that period, rendered it necessary to find substitutes. The subject was confided to the celebrated chemists Chaptal and Guyton de Morveau, when it was found, that France possessed many quarries in different parts, which yielded hydraulic limes nearly equal to the pozzuolana of Italy, or the volcanic tarras, or trasse of Andernach on the Rhine,—a material which the Dutch had used with great success, in combination with the lime, or cinder, of Tournay, so early as 1754, in the sluices at Flushing, and in most of the hydraulic works of Holland and Flanders.

The true theory of the action of limes with siliceous materials remained long in a state of uncertainty, until the study of it was undertaken by Vicat;[1] a brief statement of whose merits, as a distinguished engineer, is given in the Report of the Jury of the XIVth Class of the Paris International Exhibition, of 1855. In awarding to M. Vicat a 'Medal of Honour,' the jury observed, that he had devoted himself entirely to that important subject, and had successfully demonstrated, that France possessed all the elements of the pozzuolanas, and that by the simple admixture of calcined, or of raw clays, with lime, in due proportions, artificial cements, fitted for almost all hydraulic purposes, could be produced. In his extensive researches he had discovered nearly three hundred quarries in France whence hydraulic cements could be derived.

The next investigations into the subject of mortars and cements were commenced by General Treussart,[2] of the Corps du Génie, at Strasburg, in 1821. He repeated and confirmed most of the experiments of M. Vicat, differing with him only in a few un-

[1] "Recherches Expérimentales sur les Chaux de Constructions, les Bétons et les Mortiers Ordinaires." 4to. Plates. Paris, 1818. Also "Nouvelles Études sur les Pozzuolanes Artificielles comparées à la Pozzuolane d'Italie, dans leur emploi en Eau Douce et en Eau de Mer." 1846. A more complete analysis of M. Vicat's researches will be found in the Appendix to General Pasley's work "On Limes, Calcareous Cements, &c." Weale. London, 1838.

[2] "Mémoire sur les Mortiers Hydrauliques et sur les Mortiers Ordinaires," par le Général Treussart. 4to. Plates. Paris, 1829. An analysis of this work is also given in the Appendix to General Pasley's treatise "On Limes, Calcareous Cements, &c." Weale. London, 1838.

important points. Subsequently, béton, prepared after the principles thus laid down, has been used in the foundations and superstructures of almost all the public works since constructed throughout France, and the examples already quoted prove to what extent the system may be carried.

This leads to the more immediate object of this Paper, which is to introduce to the notice of English engineers, the system advocated by M. Gariel, the manufacturer of the Vassy cement, of building bridges, and other similar structures, with rubble béton, or concrete.

In the year 1832, the quarries from whence the hydraulic cement stone of Vassy is derived, were worked by Messrs. Gariel and Garnier, to such an extent, that it became necessary to rebuild and remodel the old establishment. This was done in 1833, with bricks and Vassy cement. Messrs. Gariel and Company now employ from 450 to 500 men at their works, from 400 to 500 in their public works in France and Algeria, and about 1,500 other workmen, such as carpenters, blacksmiths, and labourers, making altogether nearly 2,500 men. From 120 to 130 horses are also employed, in carrying and crushing the cement. The annual value of the cement made at Vassy amounts to about £32,000.

In the year 1849, the merits of this hydraulic cement first attracted attention, in consequence of its having been applied in the construction of a small road-bridge, composed of brick and cement, of 19·68 feet opening, with a rise of only 1·64 feet.

The works now executed in Vassy cement are extremely numerous, as shown in the "Annales des Ponts et Chaussées" for 1855, where a list of these works is given. It may be sufficient to state, that in Paris alone, there have been reconstructed le Pont au Diable, le Pont Notre Dame, le Pont d'Austerlitz, le Pont d'Arcole, le Petit Pont, and le Pont Napoleon, under the direction of the several French engineers, MM. La Galisserie, Oudry, Darcel, Savarin, Couche, and Petit, of the Corps Impériales des Ponts et Chaussées. In the year 1855, le Pont des Invalides, and le Pont de l'Alma, over the Seine, were constructed entirely of rubble and Vassy cement, with the exception of the outer surfaces, which are of cut-stone masonry. The lower surfaces, or soffits of the arches, are packed together like voussoirs, and filled in with cement.

When at Paris, during the Exposition of 1855, the Author's attention was attracted to the several bridges, which had recently been erected over the Seine, and more particularly to the Pont de l'Alma, the centres for which had only just been fixed, and the arches were about to be commenced. The engineer, M. Darcel, kindly communicated to the Author the following particulars of the structure:—

The Pont de l'Alma consists of three eliptical arches (en anse de panier) whose spans are, for the two side arches, 38·50 metres (126·23 feet) each, and the middle arch 43·0 metres (141·40 feet); the height, or conjugate axis, of the two side arches is 7·70 metres (25·25 feet), and the middle arch 8·60 metres (28·2 feet). The thickness of the arches at the centres is 1·50 metre (4·92 feet); the breadth between the faces of the arches is 10·30 metres (33·78 feet), and the total length of the bridge is 139·69 metres (458·18 feet).

The peculiarity in this bridge is the mode of construction, the materials employed being, for the hearting, or body of the structure, oolitic rubble-stone (pierre de meule), concreted by Vassy cement. The stones of the intrados of the arches were roughly squared and laid as voussoirs, whilst the rest of the structure consists entirely of rough stones, as they left the quarry, being only well washed with water, to deprive them of any earthy particles adhering to their surfaces, which would have prevented the adhesion of the cement, in which they are well bedded, and which was poured in as grouting to fill up all the interstices. The outer faces of the bridge and of the piers are built in cut stone, very carefully tooled and finished, like all the other bridges in the French capital.

The bridge only occupied nine months in actual construction, and would have been finished sooner, but for an accident which occurred to one of the piers, during a heavy flood. This injury has been since repaired, by injecting a considerable quantity of Portland cement, which has consolidated the whole structure.

The subsidences were as follow in millimetres:—right abutment, 0·6; right key arch, 0·134; right pier, 0·141; centre key arch, 0·119; left pier, 0·109; left key arch, 0·107; left abutment, 0·37.

The subsidence of the right arch was 0·61, and that of the left arch, was 0·34. The centre arch having been raised,[1] and bearing still upon its centre, could not be measured.

The right arch being the last built, the mortar was softer than that of the left arch, so that during the removal of the centering it sunk rather more.

The bridges at Paris built in this manner, upon foundations already made, cost from 300 francs to 320 francs per square metre, measured on the horizontal projection of the bridge,

[1] Some indications, however, lead to the belief that there was an error in the levelling at the commencement of the operations, and that the left pier was put at 20 millimetres too low, or the right pier at 20 millimetres too high, which would make the numbers 6—134—121—119—109—107—37. There would then have been a sinking on all the arches. Besides which, the centres sunk during the construction about 90 millimetres.

from one abutment to the other, and between the extremities. Thus, in the Pont des Invalides the lineal dimensions were—

		m.	m.
Four arches,	each	32	= 128
Three piers	„	4·5	= 13·5
Two abutments	„	11	= 22
	Total	.	163·5

The width being 16·60 metres, there was a surface of 2,714 square metres. This, at 300 francs per square metre, would give 814,200 francs, exclusive of the foundations; but as about 60,000 francs' worth of old materials were used, the cost was brought up to about 320 francs per square metre, which would have been the cost had all the materials been new. In the Pont de l'Alma the lineal dimensions were—

	m.	m.	m.
One arch . . .		43	= 120
Two arches, each	38½	= 77	
Two piers,	each	5	= 10
Two abutments	„	10	= 20
	Total	. .	150

The width being 20·60 metres, there was a surface of 3,090 square metres. This, at 300 francs per square metre, would give 927,000 francs. The actual cost, including the foundations, was 1,100,000 francs, or about £44,000. The other bridges at Paris have cost in the same proportion. Had the arches of the Pont des Invalides been entirely of cut stone, there would have been an increase of 250,000 francs for the arches alone, without reckoning the additional time required to build them, as well as stronger centres, and railroads for carrying the stone.

The mode of slackening the centres of the Pont de l'Alma, witnessed by the Author, is peculiar.

The usual mode of disengaging the wooden centres, which are generally used for carrying the arches of bridges, is by gradually slacking the wedges on which they rest, until the arches are entirely freed, when the pressure of the voussoirs becomes mutual.

In the present case, the centres rested on dry sand, enclosed in cylinders of wrought-iron, 12 inches diameter and 12 inches high. There were four of these cylinders to each rib of the framing. To the undersides of the tie-beams of each rib were attached a corresponding number of wooden pistons, so arranged as to fit into the cylinders which contained the sand. Supposing, therefore, the whole of the centres to rest entirely upon the pistons,

and the latter on the surfaces of the sand contained in the iron cylinders, it is easy to imagine, that if the whole, or any part, of the sand is allowed to flow out of holes made in the bottoms, or at the circumferences of all the cylinders simultaneously, the centres will descend also, and relieve themselves from the pressure of the arches over them, and thus allow the arches to remain in equilibrio. It is obvious, also, that the lowering of the centering can be managed with the greatest nicety, and thus any danger be avoided, from driving the wedges too much, as occasionally happens in the old system. Had the centres been rapidly removed, in this case, it would most likely, with the sinking of the piers on the right bank, have caused dangerous cracks in the masonry; but as it is, there have been only slight fissures, at the junctions of the arches with the piers and abutments. At the extrados of the arches the fissures are scarcely visible, except on the right abutment, where there is an opening of one millimetre only. The Engineer to whom this idea is attributed, is M. Baudemoulin, who adopted it in the viaduct bridge of five elliptical arches, of 20 metres span each, over the River Vienne, on the railway between Tours and Bordeaux, in 1846.[1] But this was done by means of bags of sand, supported by wedges. The substitution of iron cylinders, for the bags used by M. Baudemoulin, is a decided improvement, and the results have been perfectly satisfactory.

The Pont de l'Alma, like the other bridges recently built over the Seine, presents a remarkable example of a system of building bridges, and other public works, without cut masonry. The arches were cast, as it were, in moulds, in one piece, and held together by the adhesion of the cement. When the large dimensions of these arches is taken into consideration, the centre arch having a span of 141 feet, and a radius of curvature of 176·3 feet, an idea may be gained of the boldness of a construction which accomplishes, in rubble and cement, as much and even more than is accomplished in the granite arches of New London Bridge. How far this system can be relied upon is a question for futurity to determine. But an economy of time in construction has been proved in the cases of the bridges of Austerlitz, les Invalides, and l'Alma, and but for the interruption of the winter and floods, they would have occupied only as many months to complete, as other bridges in masonry of similar magnitude have done years.

The system of using artificial blocks of béton, for protecting the outer slopes of breakwaters, against the action of the waves of the sea, has been greatly extended at Cherbourg, Algiers, La Ciotat, and Marseilles. It has been found, that for slopes at angles of

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[1] *Vide* "Annales des Ponts et Chaussées," vol. xvii., p. 129.

45°, it is necessary to have blocks of not less than from 10 to 15 cubic metres in bulk, and many tons weight.

In England the application of rubble and cement, to ecclesiastical and feudal buildings, seems to have been as early, and as universal, as in France. It composed the foundations, walls, buttresses, and the principal parts of the fillings-in between the ribs of the vaults and crypts of most of our castles, cathedrals, and abbeys, from the time of the Romans; but the practice had never been reduced to a system, until Mr. Smeaton published his investigation on the subject, in his valuable work on the Edystone Lighthouse.[1] Mr. Smeaton's experiments were probably commenced in 1756. They are the results of that sagacity and clearness of mind which characterized all his proceedings; for although assisted by the chemical knowledge of Mr. Cookworthy, chemistry was then in its infancy. He was the first who taught the properties of English limestones, and their merits, as compared with pozzuolana and tarras, or trasse. With the use of rubble, as concrete, he was well acquainted, as he used it in the works of the Calder Canal, and had had his attention directed to it by a memorandum taken from Mr. Joseph Nickalls.[2]

Contemporary with Smeaton were George Semple,[3] in 1774, and Dr. Higgins,[4] in 1775. The first part of Semple's treatise relates chiefly to the construction of the New Essex Bridge over the Liffey, in Dublin. Having observed that a part of the gravelly bed of the river at that spot had been indurated by lime thrown down upon it, when the old bridge had been built, he turned his attention to concrete; and having studied the works of Palladio and Alberti, who explained the system used by the ancient Romans, of building walls in coffers, or cases, of small materials

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[1] *Vide* "Narrative of the Building, &c., of the Edystone Lighthouse, &c., by John Smeaton, Civil Engineer;" Book III., chap. iv., containing "Experiments to ascertain a Complete Composition for Water Cement, with their Results." Nicol. London, 1791.

[2] "The following composition I directed to be used in building the first lock upon the River Calder, in the year 1760; and which I lately transcribed from the memorandum-book of Mr. Joseph Nickalls, Civil Engineer, at that time resident surveyor of the River Calder.

		Measures.
For face mortar—	Barrow Lime . .	4
	Ground Minion . .	2
	Coarse Sand . .	2
	Fine Sand . . .	2

And for the rubble backing; to the above composition, add eight measures of small gravel, or pebbles, the largest not larger than a horse-bean; which application of pebbles was taken from what I observed at Corfe Castle."—*Vide* Smeaton's "Narrative of the Building, &c., of the Edystone Lighthouse," &c., p. 118.

[3] *Vide* "A Treatise on Building in Water," in Two Parts. Dublin, 1776.

[4] *Vide* "Experiments and Observations on Calcareous Cements, and of preparing Quicklime," &c. &c. By Bryan Higgins, M.D. London, 1780.

grouted; he proposed to follow the same plan in the foundations of bridges and other works.

Dr. Higgins' book gives a detailed account of his first investigations, in 1774, and the continuation of them during several years subsequently. His experiments, in 1778 and 1779, on the proportions of lime and sand best suited to make good mortars, on the effect of earth and metallic oxides, on bones and chalk limes, and stone limes, on stuccos, and on the concreting of gravel with lime, for making artificial stones, or for the surfaces of roads, possess considerable merit.

In 1796, Mr. James Parker, of Northfleet, took out a patent for making certain cements, to be used in hydraulic, or other buildings, and for stucco work. He describes his cement as being obtained from certain stones, or argillaceous productions, or nodules of clay. This stone was termed Sheppy stone, from being found near that island. The stones were burnt in kilns, and afterwards ground to powder, which was found to possess the peculiar property of hardening under water. Mr. Parker denominated it Roman cement, and under this name it was almost universally used for constructions under water, by engineers and architects, to the exclusion of many of the best English hydraulic cements, such as lime from Aberthaw, Halling, Dorking, and other places, though these were subsequently much used by Jessop, Chapman, Telford, Rennie, and others. The properties of these cements have since been eclipsed by the Portland cement of Messrs. Bazley, White, and Co., whose investigations on this subject are recorded in the Minutes of the Institution.[1]

The next and most valuable experiments on calcareous stones, limes, cement, and concrete, are by Major-General Pasley. They were commenced in 1826, continued with unabating zeal and sagacity, through a long series of years, and are recorded in a treatise[2] in which he details the history of the subject, and his own conclusions. The General, however, in attributing the introduction of concrete, in the foundation of the Penitentiary at Millbank to Sir Robert Smirke, falls into an error, which requires correction. On referring to the original correspondence which took place between the late Right Honourable Sir Charles Long, one of the supervisors appointed by Parliament to overlook the Penitentiary, it appears that on the 22nd of January 1813, the late Mr. Rennie, in conjunction with Messrs. Lewis, Cockerell,

[1] *Vide* Minutes of Proceedings Inst. C.E., 1851-52, vol. xi., pp. 478 to 510.

[2] *Vide* "Observations on Limes, Calcareous Cements, Mortars, Stuccos, and Concrete, &c.," by Major-General Sir C. W. Pasley. 8vo. London, 1838, and 2nd Edition, Part I., London, 1847.

and Browne, architects, made a Report on the foundations of that building, of which the following is a copy:—

"We, whose names are hereunto subscribed, have, at the request of Thomas Hardwick, Esq., architect, viewed the land adjoining to Millbank, Westminster, whereon is intended to be erected Penitentiary buildings, for the purpose of giving our opinion upon the most proper construction of the foundations hereof, considering the nature of the soils under the site of the said buildings, and also of the bounding-wall round the same.

"We have seen the plans of the intended buildings, and the borings of the soil, ascertaining the strata beneath, by which it appears, that nearly one-half of the substrata consists of alluvial soil, being a compound of vegetable earth, light clay, and moor log, to a depth varying from 7 to 12 feet below the present surface, at which depth a sound gravel appears to prevail. And we are of opinion that the earth under the actual site of the whole of the buildings should be excavated to the gravel, and a mass of puddled walling, of a breadth exceeding that of the lines of buildings, be formed, instead of the earth so excavated, to be continued up as high as within two feet of the intended surface to which the areas are to be raised, the puddle walling to consist of gravel or ballast only, having perpendicular sides, and mixed in lime water, with a small quantity of sand, upon which the buildings may be erected with security.

"We are of opinion, that the boundary-wall may be erected without sinking through the alluvial soil to the gravel, except where it is very near the surface, by taking out the upper soil and a small part of the clay only, and preparing a rubble foundation-stone wall rammed and made at least 2 feet in height, upon which the wall may be erected, with a broad footing and inclined sides, from the surface of the ground upwards.

"(Signed) JOHN RENNIE.
JAMES LEWIS.
S. P. COCKERELL.
ROBERT BROWNE.

"*London*, 22*nd January*, 1813."

The conclusion, therefore, is that the foundations of the building, and the walls of the Penitentiary, were made in concrete and gravel, for the first time, and that Mr. Smirke was not called in until the 20th December, 1816, and then at the request of Mr. Rennie. Mr (now Sir Robert) Smirke is justly entitled to the merit of carrying out a system which has so well succeeded under his careful management, but he was not the introducer of it, either at the Millbank Penitentiary, or previously. Mr. Rennie had

practised what he termed grouting, in most of his early works, but his subsequent practice was carried out more carefully, by making his masonry more solidly and better jointed. He preferred piled foundations to those of concrete, and the result has been the security of the foundations of all the bridges erected by him, as well over the Thames as elsewhere.

The Paper is illustrated by numerous drawings and models of bridges constructed of rubble and Vassy cement, and of the mode of lowering the centres of the Alma bridge, and by specimens of the concrete formed, exhibiting its hardness and soundness.

Mr. RENNIE, in commencing the discussion, gave some further details of the works which had been alluded to, and particularly of the Pont de l'Alma. He stated, that the material composing the arches of the Pont au Diable, which consisted of one part of Vassy cement to two parts of sand, was found originally to dry so irregularly as to cause cracks in several places. This was remedied in the next bridge, by forming large detached, wedge-shaped, blocks of the concrete *in situ*, of the full width of the bridge, after allowing for the outer rings of cut masonry, and then cementing them together. But a further improvement was made. It was found, that in making an arch of nearly 5 feet in thickness, there was unequal expansion and contraction of the materials. To obviate this, a ring of small stones roughly squared, and set in cement, was first laid, on which the coating of Vassy cement concrete was spread. In fact the arch was built in two rings. It was stated that the Pont de l'Alma had cost £44,000, but he believed that the sum of £50,000 was nearer to the actual expenditure. Now, a bridge built from his designs at Liège, of dressed stone throughout, and piled foundations, 550 feet in length and 30 feet in width, or 60 feet longer and half the width of the Alma bridge, had cost only £26,000. This comparative statement did not exhibit any great economy in cost, in favour of the use of concrete; but there was a gain of time, as the Pont de l'Alma was built in nine months, as stated in the Paper, whereas the Liège bridge occupied three years in its erection.

Mr. R. RAWLINSON presumed, that the Paper was to be taken as a history of rubble and concrete up to a certain date only, for it did not convey any idea of the extent of their use at the present time. There were now existing, in various parts of Great Britain, some remarkable works in rubble masonry, which had not been alluded to, especially at the Liverpool and at the Birkenhead Docks. The ashlar masonry in the Liverpool Docks cost about twenty-five shillings per cubic yard; the stones were most accurately dressed, and such attention was paid to laying them, that the blade of a penknife could scarcely be introduced at the joints. The rubble masonry, of which river and dock-walls were constructed, only cost from ten to fifteen shillings per cubic yard. He was glad that the attention of the Institution had been drawn to working in rubble, which, in his opinion, had been greatly neglected, engineers having gone to the opposite extreme of building in expensive ashlar. He had seen rubble masonry two thousand years old. The side-walls and arches (without groins), of reservoirs built at Sinope, in the time of Trajan, were entirely of rubble. Their present state of ruin was not attributable to natural decay. The most enduring works in this country and on the continent of Europe were invariably those in which small stones (wallstone—

without ashlar quoins) and about one-third mortar had been used. The old castle at Newcastle-upon-Tyne was an example, the inner arches being formed of rubble. But what was to be most carefully guarded against was the adoption of a hybrid style of masonry, consisting partly of ashlar and partly of rubble. This was a dangerous system, as unequal settling was almost sure to cause the ashlar facing to split, or to part from the rubble backing. The weakest masonry walls at the Liverpool Docks were those faced with hewn ashlar and backed with rubble; the strongest walls were composed wholly of rubble, the face-work consisting of granite rubble, backed with new red sandstone, from Runcorn and other quarries. Mr. Hartley had adopted rubble, after great experience.

Mr. Penrose was quite prepared to admit the value of rubble masonry, when made of proper materials and well put together. This was attested by many ancient Gothic and Norman buildings. At the same time, there were buildings in Athens constructed of blocks of solid marble, with rubbed joints, which had endured perfectly for many ages. He entirely concurred in the recommendation to avoid the use of ashlar and rubble together in the same structure. He had seen Roman and Norman buildings, where the ashlar facing had fallen away, and the whole work depended upon the rubble hearting.

Mr. A. Giles said he had used concrete in large quantities, for foundations and for the back of retaining-walls; and in such cases it had not cost more than one-fourth what rubble would have done. He had known instances of walls being carried away by a slip, which would have remained perfectly stable, if they had been made heavier by using concrete. It was a generally-received opinion, that concrete made with carefully-washed gravel and sand, was preferable to that which contained an admixture of loam. Now, in his own experience, this had been proved not to be the case, for loam had been used with positive advantage. If expensive processes of making concrete were adopted, it would be better to resort at once to rubble-work.

Mr. G. R. Burnell said, it had been shown, in a remarkable Paper in the 'Annales des Mines,' that the composition of the sand ought to bear some relation to that of the lime with which it was mixed, and that under certain circumstances the presence of marl in the sand was necessary. A careful examination of the treatises on the subject of rubble masonry, showed that little was known as to the weight it would sustain, or the duty it would perform. About forty years ago Mr. Rennie made some valuable experiments, upon the crushing weights of different materials; but they did not solve the practical questions which engineers had sometimes to deal with. The failure of the Barentin Viaduct, on the

Havre Railway, was a remarkable case: this was built of rubble limestone, set in chalk-lime, and its fall was occasioned, simply, from the crushing of the foundations, the weight upon which was about 56 lbs. per superficial inch, or more than 3½ tons per superficial foot. It was of great importance to ascertain the resisting powers of rubble, composed of different materials, and set in different limes, and cements; and also the composition and action of the ingredients which entered into the concrete, or which were mixed up with the rubble. The concrete, composed of White's Portland cement and shingle, forming the massive blocks used in building the piers and harbour-works at Dover, Alderney, Cherbourg, and other places, demonstrated the great solidity attained by these masses, which enabled very extensive works to be constructed with great rapidity. He regretted, that Mr. Rennie had not directed attention to the extraordinary works constructed at Toulon, in 1850, where in a depth of 42 feet of water, a large graving-dock had been built, the whole of the hearting of which was executed in concrete. Probably in the course of the next Session, he should be in a position to give a short account of these works, and of the investigations he had referred to, as having appeared in the 'Annales des Mines,' upon the materials used in constructions in sea-water.

Mr. VIGNOLES remarked, that a distinction ought to be drawn between concrete, or béton, and rubble-work. Although they were frequently applied to similar uses, generally speaking concrete, as it was termed by the English, or béton, as it was called by the French, was used for foundations, or for forming an apron between the piers of a bridge, to prevent the evil effects of scour, and also in breakwaters, where large masses of that material were thrown in. He had used béton in Russia on a large scale, where it was subjected to a pressure of 5 tons per square foot. It was made of a particular clay, burnt according to the formula of Vicat, and thus a perfect artificial hydraulic lime had been formed, nearly equal to natural lime. In rubble-work, the stone formed about three-fourths, or five-sixths, of the whole mass, whilst in concrete, the proportion of stone was very much less. In this respect the material of ancient buildings occupied a place between the modern concrete and rubble, for in the works of the Romans the stone formed about one-third of the whole mass. Each, therefore, formed a different character of building, applicable under different circumstances,—and each should be considered on its own merits. His own belief was, that concrete was better adapted for bearing superincumbent pressure, as in foundations, than for the construction of bridges.

Mr. J. SIMPSON observed, that the river wall, 1,200 feet in length and 25 feet in height, in front of the new works of the

Chelsea Water Company, at Seething Wells, near Kingston-on-Thames, was formed of concrete, composed of one part of Dorking lime, and eleven parts of sand and washed shingle. A cubic foot of the same materials and density was found to weigh 136 lbs., or very nearly equal to that of a cubic foot of Bramley Fall stone, which weighed 138 lbs.

Mr. WALKER said, that his uncle, the late Mr. Ralph Walker, in which he was supported by Captain Huddart, had used washed gravel, without lime, for the backing of quay walls at the East and West India Docks and other places, by which great solidity was attained. The late Mr. Rennie subsequently introduced the use of lime with the gravel, forming concrete.

Perhaps the most extensive application of cement concrete was at the Dover Harbour of Refuge, where no proper stone was to be obtained in the neighbourhood. The concrete was composed of one part of Portland cement mixed with ten parts of shingle and sand, moulded into blocks varying from 6 to 10 tons in weight. The blocks could be formed of any size and shape desired, and became very hard in a short time. The general dimensions of the Dover breakwater were: medium width 80 feet to 90 feet, composed of a hearting of cement concrete blocks, resting upon Roach Portland stone, and faced with granite, of an average thickness of 5 feet to 6 feet on each side. The foundation of the wall was 62 feet below high-water of spring tides, or 43 feet below low-water of spring tides, and the top rose to 25 feet above the former mark, making a total height of 87 feet. The operations were carried on up to low-water mark, by means of diving-bells.

At Alderney the depth of the water was greater than at Dover, and there was abundance of rough stone, which was thrown in as "pierre perdue" to form the substratum, as a vertical wall was not required for the full height. From a depth of 12 feet below low-water, a nearly vertical stone wall was brought up, backed by concrete blocks, up to low-water mark.

It had been observed, that the quality of the Portland cement was not always uniform, and that expansion, or disintegration of the blocks, had taken place two, or three months after they were made, and before they were bedded in position, which operation was generally delayed for six, or nine months, to prove them, and to allow them to become thoroughly dry. The manufacture of Portland cement was evidently one which required much care, and was not free from risk, though its general employment was satisfactory, and its use was daily extending, for works of civil engineering and architecture.

Mr. G. F. WHITE said, with regard to the works at Dover, that though nearly half a million cubic feet of concrete in blocks were

now laid annually, the proportion of breakage scarcely exceeded one per cent., so that there could not have been a great deal of the cement rejected. The cost of the concrete blocks was, he believed, about one-half what would have been the cost of Roach Portland stone, of which the walls were originally intended to have been constructed. The prominent advantages of the use of these blocks were their large cubic contents and consequent weight, the uniformity of their size, and their close contact in the finished work.

The French engineers had used concrete blocks, made of lime and artificial pozzuolana, at Marseilles, Rochefort, Algiers, and Cherbourg. After a few years' exposure to the sea-water, these blocks had disintegrated and fallen to pieces,—a result ascribed by M. Vicat to the presence of magnesia in the sea-water, which acted injuriously on the lime. It was not without hesitation, therefore, that some years later, they had commenced the employment of Portland cement for their béton works; but the results ascertained in the interval, as to its durability, when exposed to the action of sea-water, appeared to have justified the present general adoption of that material, even to the extent of using the blocks in external walls, without the protection of stone casing.

The injection of Portland cement into the foundations of the Pont de l'Alma was a method of forming béton under water, which, though allowable in exceptional cases, could not be recommended on the score of economy, as in the case in question a quantity of cement, costing not less than £1,500, had been employed, one-third of which had, in all probability, been washed away by the current, and had never become indurated.

Mr. GREAVES remarked, that the Paper would have been more useful, if it had stated the length of time that was necessary to impart sufficient solidity to these concrete blocks, before they could bear the weight to be placed upon them. Concrete had been by no means sparingly used in this country; but it was, for the most part, employed for foundations, and other work out of sight. It was seldom used in exposed situations, where it was liable to be influenced by atmospheric changes, as engineers were not generally aware of the length of time it took to indurate, or the degree of induration it acquired. He thought it desirable, when speaking of concrete, that the kind of material alluded to should be properly described. What was understood by concrete, in this country, was a mass of materials, well mingled, thrown as from a height into a foundation, and allowed to consolidate. Now, this was evidently not the same material which had been lately used in such cases as the harbour-works at Marseilles, as there the stone and cement appeared to have been gradually packed by hand, in the moulds in which the blocks were made.

When examining the ruins of Rome, he was surprised to find the extent to which concrete had been used there, and durability being an evident result in the construction, it had at least contributed to the application of the term "Eternal city." He had provided a delineation of arches as seen in the ruins, in which a gradation might be observed in the quantity of concrete practice had introduced into the work. Arches from the palace of Nero, where the flat bricks, or rather tiles, were laid close together, exhibited what he meant. On one side of some of the arches there were spaces of 2 inches containing—not exactly concrete, but mortar—as it were at the commencement of the idea of using concrete for the purpose. Another instance went to a further extent. It was an arch of 10 feet span, in the ruins of the baths of Dioclesian. The spaces between the tiles were 10 inches wide, and the whole face of the brick-work was abraded, so that the delineation of the interior was quite clear; the pieces of stone, used in forming the concrete between the tiles, were in a horizontal position, and did not leave room for the idea of thrust in the smaller pieces themselves. In another arch of the same description, the span of which was 17 feet, the tiles were about 2 inches thick; and between each pair there was about 10 inches of something very little better than concrete. In the remains of the Basilica of Constantine, or the Temple of Peace, there were three arches of 75 feet span each, and about 20 feet deep. These arches formed one whole side of the building. The mode of executing the work was very apparent. At the two extreme ends were strong arches carried round in two rings of Roman bricks, each 18 inches square and about 2½ inches in thickness. The interior of these ribs ran about 5 feet in depth. There were also four ribs, each 2 feet wide, between the two extreme ribbed arches. These ribs ran entirely across the cylinder, and appeared to have been constructed in the same way as the larger ones, but of smaller dimensions. Between these ribs the concrete, or rubble-work appeared to have been placed. There were broken apertures which showed that the work, between the ribs of brick-work, had not the character of an arch in it. The stones were laid horizontally, and appeared to have been thrown into mortar in a very liquid condition. The ornamental coffers in the soffit had been made at the same time, being cast on a moulded centering, which had probably been supported by, or had rested upon, the arched ribs. The use of concrete to this extent was, he thought, beyond what had been ever contemplated in this country, probably on account of the climate of Italy enabling the concrete to dry so much more rapidly and effectually. Another instance was a dome of about 72 feet,—another was a cylindrical vault of about 75 feet span. The ribs were some distance apart, and a series of diagonal ribs was intro-

duced; but the whole spandrel was composed of concrete, and the structure more resembled a girder, than an arch. The frequency of these remains in the ruins of Rome conveyed the notion, that they had no idea of vaulting with a continuous arch, although the arch was familiar to the Romans, as was evinced in the splendid structure of the Coliseum. The arches were turned well so long as they ran in a longitudinal line, but when a space was spanned over, it was done with a material much resembling what was now called concrete. The lime was procured from the Apennines, and the stone almost invariably used was tufa, which was selected on account of its light specific gravity. In the Coliseum the circumferential thrust balanced itself, but the radial thrust was avoided by the use of a series of concentric vaults, constructed as already described. The dome of the Pantheon consisted of arched ribs running from the base to the apex, or rather to the centre ring; the spaces between the ribs, tapering to the point, being filled very much in the same way, and coffered in the soffit like the arches in the Basilica of Constantine. He was not prepared to say there was no arch in it, but his idea, from observation, was that they set up the ribs for a frame, and then filled up with a hardening material, to produce a complete dome. With reference to the use of pozzuolana, he believed it was used instead of sand; it was found in abundance near Rome, was about as hard as marl, and the extensive ramifications of the catacombs were attributed to the enormous excavation of this material.

Mr. G. F. WHITE said, that in the Session of 1851-52, he had given a description[1] of the mode of manufacture of the blocks used in the works at Cherbourg, which were made in precisely the same manner as those at Marseilles. These blocks contained about 700 cubic feet, and weighed 52 tons each; they were built up within a mould, and when dry they were floated to their destination by means of caissons, and deposited in their proper places. It had been imagined, that the waves could not lift blocks of that size, but, in some instances, they had been rolled a distance of 30 feet, or from the bottom to the top of the breakwater. The plan of making concrete in France was different to that practised in this country. It almost always contained, as was the case at Alderney, a large proportion of stone. The mortar, composed of one part of lime to two parts of sand, was first made, then an equal quantity of gravel was added, and then the stone, which occupied, in proportion to the whole mass, something like 40 per cent. of the bulk.

The concrete used in forming the blocks at Dover was composed entirely of shingle, sand, and Portland cement; it was

[1] *Vide* Minutes of Proceedings Inst. C.E., 1851–52, vol. xi., pp. 478 to 510.

formerly mixed by hand, but within the last few years a large drum revolving diagonally had been used, so that the amalgamation of the materials was as complete as possible. The theory of all good concrete was to coat every particle of stone, or gravel, with a film of the cement, and that could only be thoroughly effected by machinery. As a proof of the strength of the blocks, he might mention, that although they were allowed to remain for six, or nine months before they were used in the works, yet they were lifted in three, or four days, and were placed in stock, which could not be done unless they had become perfectly consolidated.

Mr. R. J. HOOD had noticed a large amount of expansion in Portland cement. At the Sydenham Station, a retaining wall, built of brickwork, set in the cement, 20 feet in height and 6 feet in thickness, expanded between 2 feet and 3 feet in a length of 100 feet. The bricks were in some places lifted up bodily, as if they had been blown up by gunpowder. As some portions of the wall stood very well, he conceived there must have been some error in the manufacture, or in the use of the cement. The persons who supplied it attributed the failure to the cement being used too fresh from the kiln, but the same results occurred, after the cement had been kept some time before being used. The same fact had been noticed, in a thin coat of stucco made of similar material, which, in a few days, was extended in width from 9 inches to 11 inches.

Mr. GREAVES mentioned a similar instance of expansion, which had occurred to the coping of a brick wall, set in cement. The coping, which was of brick on edge, set in Portland cement, expanded 9 inches in a length of 70 feet, and dragged away 12 inches of the upper part of the wall.

Major-General Sir CHARLES PASLEY said, it was well known, he believed, that he had made many experiments in the manufacture of artificial cement, and that he was the first to bring it to any degree of perfection. The cement made by him was composed of chalk and the blue alluvial mud of the Medway. He had recommended the Messrs. White to make cement according to the rules he had laid down, which he told them, would produce an artificial cement, that would bring as good a price in the market as natural cement. At first, however, they preferred the natural cements of Sheppy and of Harwich, though they were merely stones, until burned and ground in a mill, and mixed with water. They afterwards adopted the same ingredients which he had used, but, sinking the term artificial, had disguised the cement made from these materials, under the name of Portland cement, so that he was not aware of the similarity, until he was present at the trials of the cement, at the Exhibition of 1851. An Austrian engineer who had witnessed these trials, and who had read and perfectly under-

stood the "Rules for Making an Artificial Cement, equal to the best natural cements of England," laboured under the same mistake. The Portland cement was not in his opinion any improvement, but the contrary; it was uncertain in its quality, being sometimes good and at others bad, resulting from the injudicious system of burning part of it moderately, and part of it to vitrification, and then mixing the two kinds together. The architect who erected the model cottages in Hyde Park, near to the Exhibition of 1851, was of that opinion, so that he never made use of it.

In respect to concrete, Sir Charles maintained his former opinion, that Sir Robert Smirke was the first person, who actually employed concrete, in England, in the way in which it was now used for the foundations of walls. He had inquired carefully into the subject, before making the assertion, in his Treatise on Cements, and he was prepared to defend the correctness of his statement.

Mr. WALKER said, the cause of the failure of some of the cement blocks, to which he had alluded, and the cases of expansion, which had been noticed, probably arose from the presence of too much lime in the cement—the result of careless, or improper manufacture, an error not unfrequently made by inexperienced manufacturers. The lime so found in a free state, and not well incorporated with the other ingredients, would undergo the action of slaking by the atmosphere, and still more rapidly by sea water, and disintegration would ensue.

The now too general system of using a quantity of carbonate of lime in the manufacture of bricks was injurious; as the lime, when acted upon by damp, or water, expanded, split the bricks, and destroyed the work. In consequence of this action going on to a dangerous extent, in a lighthouse constructed of bricks, he had been obliged to have the building entirely pulled down.

Mr. G. R. BURNELL believed, that the stability of the domes of the Coliseum and of the Pantheon, at Rome, depended entirely on the adhesion of the materials, and not upon the arch form in which they were constructed. At all events, this was certainly the case in Persia, where the domes frequently extended beyond the points of support. The application of concrete for building purposes, where the adhesive quality of the material itself was particularly called into play, was to be found in some buildings of the mediæval ages. In Rochester Castle, some portions of the staircase were entirely of concrete; it seemed to have been formed in a species of mould, almost in one piece, the structure depending upon the adhesion of the materials of which it was composed.

With regard to the burning of the pozzuolana, it should be stated

that natural pozzuolana was itself a volcanic material—silicate of alumina calcined in the bowels of the earth. The artificial pozzuolana of France, which was composed simply of burnt clay, succeeded well enough in fresh water, but when used in salt water it invariably failed. The real difference between natural and artificial cements consisted in the burning, which resulted in an essential chemical change. Artificial hydraulic lime was a mixture of chalk and clay, which was burnt to the extent of driving off the carbonic acid, and it then became a valuable hydraulic lime, but it would not form a cement which would resist the action of sea-water. As regarded the reported failures of Portland cement, he thought they arose entirely from carelessness in the selection of the ingredients employed, and in the methods of manufacture. If there was any sulphur, or sulphate of lime in the clay, it would not at once enter into combination with the lime, but would have a tendency to disintegrate at a later period, and to produce the expansion which had been spoken of. He believed the failure of some of the blocks at Cherbourg was owing to this cause. The manufacture of this cement was essentially one of confidence, and such defects as those mentioned rarely, if ever, occurred with the produce of experienced manufacturers.

Mr. C. MANBY, Secretary, directed attention to a work that had been lately published, entitled "Travaux d'achèvement de la Digue de Cherbourg," by M. Joseph Bonnin, the Resident Engineer charged with the execution of those works.

The detailed account given by M. Bonnin of the construction and employment of concrete blocks at Cherbourg bore upon the present discussion, and would be found to have special interest for engineers engaged in works of a similar character.

Numerous experiments had been made, prior to the year 1856, on the materials best adapted for the formation of artificial blocks, which were required at Cherbourg to be of extraordinary size and weight, in order to fulfil the twofold condition, of being themselves immoveable, and of keeping down the rubble-bed on which they were laid.

Artificial asphalte, composed of coal-tar, lime, and sand, had been tried on a small scale, and was found to present some advantages; but it had been abandoned, on account of the uncertainty as to the lengthened action of sea-water on such a composition.

The employment of clays vitrified into masses was more favourably received; but how to arrive at burning to the centre of blocks of 700 cubic feet, or where to find the proper fusible materials combining the needed conditions of density and price, were the obstacles to the adoption of such a scheme. The idea had not, however, been finally abandoned, until inquiries had been made at Naples, whether the lava of Vesuvius could be extracted in blocks of suffi-

cient size, and as to the means of transporting them to France: the reply to this was, as might be anticipated, that, though theoretically possible, the expense would be a prohibition.

Recourse was next had to the limes of the neighbourhood mixed with pozzuolano, and to the hydraulic cements both of France and of England.

After repeated trials, the blocks made of cement seemed to present the best guarantees of unalterability, and the materials ultimately selected for use had been the Portland (artificial) cement, made by Messrs. White and Sons, of London, and the Medina (natural) cement, made by Messrs. Francis, of London; but here had arisen another difficulty.

The rapid setting of the natural cement, especially in hot weather, had been such as to prevent its manipulation in sufficiently large quantities at one time, while the Portland cement, on the other hand, had set too slowly for the operations of tide-work. Under these circumstances it had been considered, that a mixture of the two cements would counteract the defects of both, the ascertained durability of each cement used separately inspiring the conviction, that the same property would attend their combination; and though this proceeding had been condemned by many engineers the results would seem to have been justified in practice, for, after the expiration of nine years, blocks exposed on the fore-shores of the jetty-heads had shown the marks of the trowel, and presented "arrises" as sharp and fresh as on the day of immersion.

The proportions of mixture of the two cements had varied from one-third of Medina and two-thirds of Portland, to one-fourth of Medina and three-fourths of Portland; and the sum of resistance of the blended materials had been proved, by experiment, to be intermediate between that of the two elements composing the mixture.

In this way more than three-fourths of the work had been executed. The average capacity of the blocks employed had been 20 cubic metres, or 700 cubic feet each, weighing about 45 tons; and the number used, between the years 1846 and 1853, had been about two thousand, representing a cube of more than 40,000 metres.

M. Bonnin's work contained a minute analysis of the cost of these béton blocks, the details of which it might be advantageous to compare with similar constructions in this country.

41,160 cubic metres of artificial blocks had cost, at 55 francs per cubic metre, 2,263,800 francs; equivalent in English measure to 1,400,000 cubic feet, at 16*d.* per cubic foot, £93,000.

This price had been composed of the following items:—

Each block of 20 cubic metres had contained—

	fcs.	Per cube ft.
20 cubic metres of rubblestone, at per cube metre of block	4·	2d.
12 cubic metres of sand, at ditto	2·70	
	6·70	
Cement.		
1¾ tons of medina / 4 „ Portland	24·50	= 7d.
Carriage of sand and cement	8·33	= 2½d.
Waste and contingent expenses	4·72	= 1½d.
Hand-labour	6·50	= 2d.
Transport of blocks to the Digue, after making and seasoning	8·25	= 2½d.
	59·00	
Subject to a reduction in the cost of those blocks, where the dose of cement has been less—say	4·00	
Giving a mean of	55·00	= 16d.

Fifty-five francs per cubic metre, or 16*d.* per cubic foot, as the average cost of the blocks in situ.

Mr. R. STEPHENSON, M.P., President, congratulated the Institution upon the promise which had been made, and expressed the hope that, on a future occasion, the Members would be prepared to give the comparative prices of marine and other constructions of concrete, and of squared blocks, or of "pierre perdue," as that question had evidently been cautiously avoided in the present instance. It was a question, whether rubble concrete was really either so effective, or so cheap, as good bricks and cement, for the superstructure of a bridge, however useful it might be for the foundations, to which it had been generally restricted in this country. In such positions it was excellent, and, but for its use, many difficult works could scarcely have been executed.

He exhibited specimens of concrete and brickwork from the ruins of the Library at Alexandria, and of cement from Pompeii, which showed the remarkable soundness of the material, after the lapse of so many ages.

The large blocks of concrete, used at the new harbour works at Marseilles and at Algiers, weighed upwards of 50 tons each; they were moulded close to the spot where they were to be used, and were then thrown into the sea. At Algiers the breakwater was not water-tight, and it was evident that considerable disintegration

had taken place, as large cavities existed in the work. When the sea was agitated, it was scarcely possible to walk on the mole, on account of the jets of water which were driven through the apertures with great velocity, to a considerable distance. The local engineers anticipated, that these cavities would eventually be closed by the accretions of shells, by which several had been already stopped; but this presumed that the disintegration of the blocks would not also progress. Possibly this disintegration might have arisen, as had been suggested, from the use of artificial, instead of natural pozzuolano.

May 12, 1857.

ROBERT STEPHENSON, M.P., President,
in the Chair.

No. 965.—"Description of the Method of building Bridges upon Brick Wells, in Sandy Foundations; illustrated by the Viaduct over the River Poiney, on the line of the Madras Railway." By GEORGE BARCLAY BRUCE, M. Inst. C.E.

PREVIOUS to entering upon the immediate subject of this Paper, it may be interesting to give a few facts regarding the Madras Railway, which forms an integral part of that system of railways in India, which is now engrossing a large share of the attention of the profession, the commercial public, and the Governments of England and of India.

The Madras Railway, like the other lines in India, is being constructed by a Joint Stock Company, almost entirely with English capital, for which a certain rate of interest is guaranteed by the Government, so long as the line pays its working expenses; but any deficiency in this respect would fall on the shareholders, and be deducted from their guaranteed interest, a contingency which cannot arise, where lines are judiciously laid out and economically executed. The Government, for its own security, reserves the right of exercising a control over every department of the railway; but it is very questionable, whether having exercised the right of veto in the appointment of the officers of the various companies, the interests of the country, as well as of the railways, would not be best secured, by holding such officers responsible, and leaving the management of the various lines entirely in the hands of the companies. The only effect of constant detailed interference and supervision on the part of the Government, is to relieve the really responsible parties of their responsibility, without being able to fix it upon any one else.

The portion of the Madras Railway at present in course of construction, or opened for traffic, begins at the town of Madras, and proceeds in a westerly direction, passing Vellore, Vaniembaddy, Salem, Coimbatore, and Palghaut, to Beypoor, on the western, or Malabar coast, crossing from one side of the peninsula to the other by a line 450 miles in length, with rather heavy works and steep gradients.

The works of the Madras Railway have, from the commencement, been executed by the Company's own engineers, without the intervention of contractors, a system which, however inapplicable

in this country, has been found to answer well in Madras, both as regards the speed with which the works have been executed, and the cost at which they have been completed. The portion of the line now opened, about 65 miles in length, cost, exclusive of the rolling stock, £6,000 per mile, nearly one-half of which was expended on the rails, chairs, and sleepers.

In carrying out public works, in any country, it is desirable, as far as possible, to use the materials of the district; and though India cannot yet furnish iron for its own rails, it can, in by far the majority of instances, furnish materials for railway bridges in every way superior to iron. Acting on this principle, the Author decided on carrying the railway over the River Poiney, on a bridge built entirely of stone, found within ten miles of its site, although the position of the bridge relative to the banks on each side, was such as to present many inducements for the adoption of some kind of iron-girder superstructure.

The River Poiney, like many Indian rivers, is dry during a great part of the year, and when so, it appears to be one vast plain of sand, which the imagination can scarcely conceive ever to become the bed of a foaming torrent.

The railway crosses this river about one mile before it falls into the River Palar, and at about 70 miles from the coast. The width at the crossing is nearly 2,000 feet, and the banks of the river on both sides, for the distance of a mile, are but little, if at all elevated above the water-line.

The borings showed sand only, to a depth of 20 feet; and as there was no intention of carrying any system of foundations deeper than that, it was not necessary to continue the borings further; added to which, the means at the disposal of the engineers, for making the borings were very limited. It is not, therefore, in the power of the Author to say to what depth the sand extends; all that can be affirmed is, that there is nothing but coarse sand for a depth of 20 feet.

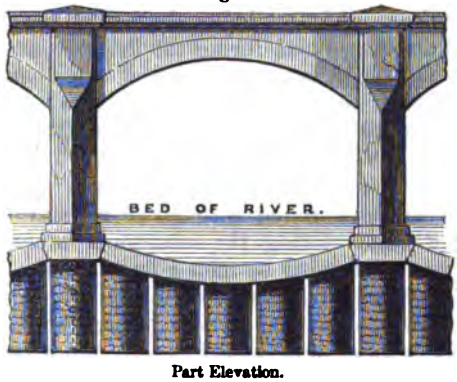
It was decided to erect a bridge of fifty-six arches, of 30 feet span each, with a rise of 6 feet, having piers 5 feet thick, built on brick wells, in the manner hereafter to be described. The width between the parapets is 25 feet. The span of 30 feet was decided on, as enabling the bridge to be kept lower than it could have been, had the span been greater, and also as being more economical and safer, where only native masons were to be employed.

In such a case as this, where there is the scour of the stream during floods to guard against, a foundation may be formed, either by driving piles down to a sufficient depth in the sand, and building the piers on them; or by driving a casing of sheet-piles round the site of each pier to prevent the sand from being washed away, and founding the pier within the dam so formed; or by means of

coffer-dams. The piers themselves may, in each case, be carried down to such a depth, as to place the foundation below the reach

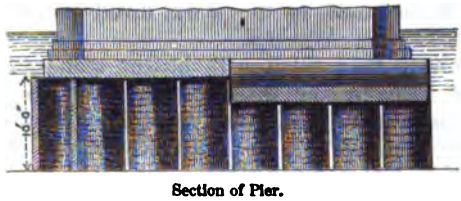
POINEY VIADUCT—MADRAS RAILWAY.

Fig. 1.



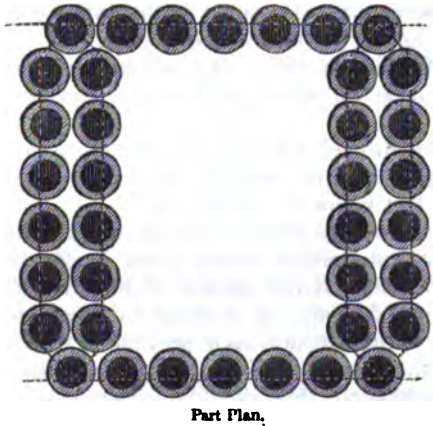
Part Elevation.

Fig. 2.



Section of Pier.

Fig. 3.



Part Plan.

of any scour. The whole of these plans would have been objection-

able, on account of their expense, leaving other considerations out of the question. Recourse was, therefore, had to the practice usually followed in Southern India, of building upon brick cylinders, or wells, sunk in the sand.

The plan pursued was this. The site of each pier was cleared to an average depth of 5 feet below the bed of the river, at about which depth water was found during the driest seasons of the year. On the site so cleared, two rows of well curbs were laid, at a distance of 5 feet 6 inches apart from centre to centre; on these, cylinders, or wells, with an internal diameter of 3 feet 6 inches, and an external diameter of 5 feet, were built with radiated bricks laid in thin clay instead of mortar. Each well was built up 5 feet at one time, and wrapped round with straw ropes, to keep all the bricks in their places during the subsequent process of sinking. The sinking was performed by men going into the inside of the wells, and excavating the sand regularly all round, the wells sinking, of course, as this was done. When the first 5 feet had been sunk, 5 feet more were added on the top of each well, and the wells sunk down to a total depth of 10 feet.

No attempt was made to keep the water out of the wells, as the men, being accustomed to the work, dived under the water to make the necessary excavations.

The wells were then filled with broken stones, or bricks, the upper 2 feet being mixed with lime and sand, to form concrete. The sand was also cleared from the spaces between the wells, for a depth of about 3 feet, and these were filled up with broken stones, but of a larger size than those used in the inside of the wells.

There were fourteen of these cylinders, or wells, under each pier, and a row of wells was also sunk in the same manner on each side of the bridge for its entire length, in a line with the ends of the cutwaters, forming a wall protection against the scour of the stream, and a base on which to rest the inverts built between the piers.

The wells thus formed a foundation extending to 15 feet below the natural bed of the river, with a level surface on which to begin the masonry, 5 feet below the natural bed.

In the present case, the river is wider than is absolutely necessary for the body of water which comes down it, for being near the junction with the Palar River, the bed of the River Poiney expands into a bell-mouthed shape, as is usual in such situations, where there are no physical obstructions to prevent it. Therefore, though the velocity of the river is considerable, there is not any excessive scour to be apprehended; but should this take place, it will be met by forming an apron of rubble-stone on the lower side of the bridge. In the case of other bridges on the Madras Railway, this

is being done, and whatever may be the circumstances of the stream, or the scour consequent upon them, a bridge built, as has been described, may be secured against casualties by throwing in rubble-stone on the down-stream side of the bridge, forming an apron on which the water, after passing through the arches, may be led clear of the foundations, without doing any damage to them.

In some cases, the bricks of the wells are laid in mortar, and left to stand for a fortnight, until it has set. The objection to the use of mortar is, its mixing with the water in the wells, and injuring the eyes of the men engaged in sinking them.

The cost of each well was as follows:—

	£.	s.	d.
Bricks	0	11	3
Well curb	0	0	9
Labour in building, filling, and sinking the well; also cost of material used in filling it	0	7	6
Lime used	0	2	0
Total cost of one well	£1	1	6

The cost of the masonry of which the bridge was built was 7*s.* 6*d.* per cubic yard, which was made up thus nearly:—

	s.	d.
Stone	3	6
Lime	0	10½
Sand	0	1½
Jaggery	0	1½
Labour in dressing stone	1	0
Ditto in setting, mixing mortar, &c.	1	3
Contingencies	0	7½
Per cubic yard	7	6

The total cost of the bridge has been about £14,000, or £7 per lineal foot.

The description of stone used was gneiss, and the plan pursued in quarrying it, was to light a fire of wood on the top of the rock, and when it became heated, the fire was removed, and water thrown on to the rock. This caused it to split off in layers, varying in thickness from 3 inches to 1 foot, which were cut by wedges into stones of a convenient size for building.

The system of building on brick wells is similar in principle to that sometimes pursued in this country, where piers are placed on cast-iron cylinders of large diameter, sunk by a process which need

not here be described.[1] The great cost of cast-iron cylinders precludes their use in India, and the object is just as well effected by the brick wells already described, at a fraction of the cost which the use of cast-iron would involve. The system is one of great practical value in India, and it is for the Members of this Institution to say, whether it might not be adopted with advantage, in certain instances, in this country.

This work was executed under the immediate superintendence of Mr. Bryce McMaster, Assoc. Inst. C.E. The Paper is accompanied by a series of diagrams from which Figs. 1, 2, and 3 are compiled.

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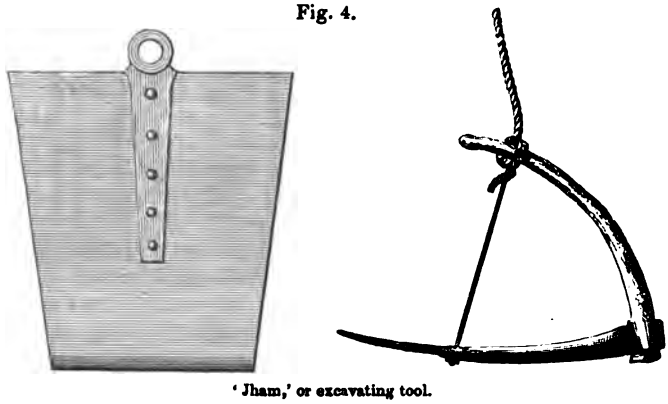
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. x., pp. 353 to 369.

[Mr. STEPHENSON,

Mr. STEPHENSON, M.P., President, said, the Paper gave a useful lesson to all engineers. It showed how the natives of the East had accomplished, what was only now being practised in this country, perhaps at a greater expense, with iron cylinders. But even with iron so cheap as in England, it appeared from the Paper, that they might hesitate, on some occasions, whether they should follow those expensive plans, or adopt the simpler and cheaper method of the natives of India.

Mr. C. MANBY, Secretary, directed attention to a Paper by Captain (now Colonel) Goodwyn, B.E., read before the Institution in February, 1842, giving an account of a similar method of obtaining foundations in Bengal.[1] His description was "As soon as the masonry (of the cylinder) has hardened sufficiently, the well-sinker fixes a plumb-line to the top of the cylinder as a guide, and descends withinside, carrying an instrument called a 'Phaōra,' or 'Mamooti,' somewhat similar in shape to a hoe; with this he excavates the earth until the water is too deep; he then commences the use of the 'Jham,' (Fig. 4,) which resembles the 'Phaōra' in

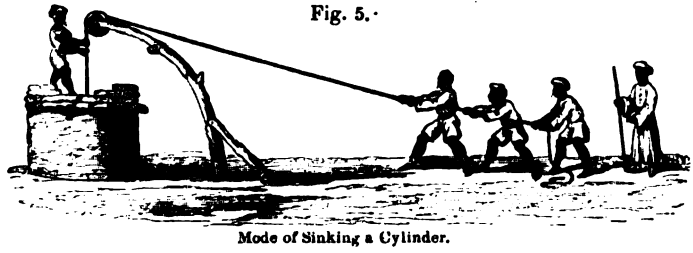
Fig. 4.



'Jham,' or excavating tool.

shape, but is about 36 inches long and 27 inches wide, and is suspended to a cord passing over a pulley above the cylinder. (Fig. 5.) Upon this instrument the well-sinker descends, and diving into the

Fig. 5.



Mode of Sinking a Cylinder.

[1] *Vide* Minutes of Proceedings Inst. C.E., vol. ii., 1842, pp. 63 to 65.

water excavates with the 'Jham' the soft earth under the sides of the curb, and is at intervals drawn up with the instrument. The cylinder descends gradually from 6 inches to 2½ feet per day, as the earth is withdrawn from beneath it, and relays of workmen keep it constantly going, lest the sand should settle around it, and cause it to hang up."

Figs. 6 and 7 show the mode in which the foundation was completed, by the capping, or vaulting of the wells, and their connexion with each other.

Fig. 6.

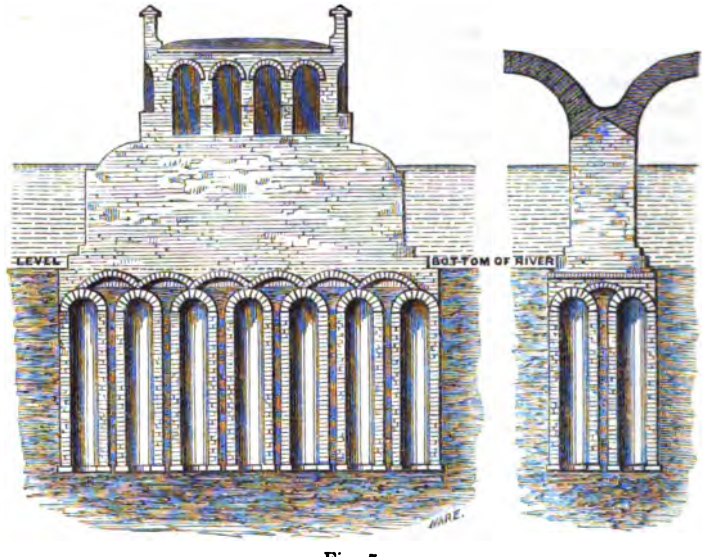


Fig. 7.

Sections and Plan of a Finished Pier.

Mr. BRUCE remarked, that he was not aware, when he wrote his Paper, that the subject had ever been brought before the Institution. There was, however, some difference in the mode described as practised in Bengal, to that followed in Madras. In the latter district, no mechanical means whatever were employed, but simply hand labour. These wells acted in a double capacity,—as piles holding by lateral friction, and as forming a mass under the building. The system was not universally applicable; for instance, in a river constantly full of water, there would be considerable difficulty in using it, in fact, other systems would probably be cheaper. The Indian rivers, which were generally dry for a large portion of the

year, could not be traversed by any other system so expeditiously, or so economically, nor the works be otherwise rendered so permanent. In speaking of economy, he referred to a case in Madras, where bricks cost about 6*s*. per thousand, and brickwork from 6*s*. to 8*s*. per cubic yard; timber was very expensive. The bricks were burnt with small jingle wood. This state of things would be reversed in this country; but there were cases in which it might be applicable even in England.

Mr. HAWKSHAW, V.P. remarked, that the process followed at Madras seemed to differ from that employed at Bengal, inasmuch as the wells in the latter case appeared to be coved over, and the weight of the superstructure to be thrown upon the outer walls of the cylinders; whereas, in Madras, the wells were filled up with material which rendered the whole a solid mass, or column upon which the weight was uniformly distributed.

Colonel Sir FREDERICK ABBOTT alluded to what he considered an improvement, introduced by Colonel Colvin, in the North-West Provinces of India. He had found that when the wells were sunk in deep sand, with a heavy load of water, the sand was liable to pass through the interstices, and there was a difficulty in keeping the wells straight. He had, therefore, rejected the well system, and instead, had formed square, or elongated masses of brickwork, like a solid wall, perforated with a number of small holes, by means of which the well-diggers got in to excavate the earth underneath. This method was cheaper, more solid, and more rapidly executed. This plan had been further extended by Colonel Sir Proby Cautley, who had made each mass of the full size of the foundation of the structure to be placed on it; in this way he established the piers of the great Solani Aqueduct on the Ganges Canal. It had been said, that the well system was not suited to rivers in which water was constantly present. This difficulty might, he believed, be overcome, where there was only a moderate body of water, by surrounding the space to be occupied by the pier with light, sheet piling; then filling up the "enclosure" with sand to above the level of the water, and proceeding to construct on it, as if it were the dry bed of a river. Some engineers filled in the wells with loose rubble, with the object of providing for any sinking away of the sand from beneath the cylinders, which frequently occurred, as the foundations were placed on the sandy beds of rivers which were dry in certain seasons, but became torrents at other periods. Depths of from 20 feet to 30 feet of sand were not unfrequently washed away, and it had, therefore, been necessary in some cases, as for instance in the suspension bridges near Delhi, to carry these wells down as deep as 40 feet in one abutment, and 34 feet in the other abutment. Here, on one occasion, the ground was excavated to within 8 feet of the bottom of the wells, but yet the foundations remained perfectly sound.

May 19, 1857.

ROBERT STEPHENSON, M.P., President,
in the Chair.

THE following Candidates were balloted for, and duly elected :— Lieut. GEORGE HENRY BASEVI, WILLIAM CHRISTOPHER BENNETT, CHARLES PERCY BYSSHE SHELLEY, and JOSEPH WRIGHT, jun., as Associates.

No. 967.—"On the Disturbances of Suspension Bridges, and the modes of counteracting them." By AUGUSTUS STEPHEN LUKIN and CHARLES EDWARD CONDER.

SUSPENSION bridges, requiring considerably less material for their construction than girder bridges, and being practicable for far greater spans, than have ever been attempted with structures of a more rigid nature, would probably be frequently employed for railway traffic, as well as for other purposes, were they not so liable to disturbances of various kinds.

The chief sources of danger arise from the mobility, or flexibility of the suspension chains; and the movements so produced may be thus enumerated:—

1. Undulations, or distortions produced in the main chains by an unequally distributed, or a passing load.
2. Effects of agitations, or distortions of the main chains in vertical planes, reacting on the roadway.
3. Oscillation, or transverse swing.
4. Distortion of the lines of the main chains, when there happens to be only a small load on the platform, owing to their tendency to assume the catenary, or other curves natural to them.
5. The unequal strains in different bays, incident to bridges of more than one span.

Various modes may be suggested for meeting these difficulties. The tension and weight of the main chains may be increased to such a degree, as to reduce, within narrow limits, their liability to disturbance from a passing load. But, by so increasing the mass of the chains, there ensues an augmentation of danger to the rods and roadway, when the chains are swung and agitated by storms. The question of cost, also, will preclude the employment of much more material in the suspension chains, than is required for the support of the maximum load. It is, therefore, only in great spans, where the chains necessarily become very massive, that

their simple weight can be expected to impart considerable steadiness to the structure.

The reduction of the deflection of the curve will have an important effect, in diminishing the undulations and distortions induced by the suspended load, as well as in lessening the liability to swing. As the deflection is reduced, however, the tension is increased, rendering necessary a corresponding increase in the strength of the chains, so that economy assigns certain limits to this mode of steadying the superstructure.

If attention is directed to the roadway, it will be seen, that there is advantage in giving it a certain degree of stiffness, combined with elasticity; as a pressure on any point of the platform will then be communicated to several pairs of rods, so as, in some degree, to equalise the effects of irregular, or traversing loads. The question next naturally arises, whether the stiffness of the roadway should not be sufficiently increased to insure complete immobility, by resisting the agitations of the chains. Opinions have been given against the advisability of thus combining an absolutely rigid structure with suspension chains, considered simply as a question of permanent stability. An objection also lies against such a bridge in point of economy, since the material employed in giving sufficient strength to the platform might be expected to go far towards the construction of a girder bridge, entirely independent of chains.

The Niagara Falls Suspension Bridge owes the steadiness which it is said to preserve, under railway traffic at a low rate of speed, in a great degree to its having separate platforms for the railway and the roadway; each being suspended from a pair of main chains. One of these platforms being below the other, they are firmly braced together, so as to form in effect a very deep girder. The stiffness of the structure is further secured by stays, some of which extend from the platform to the tops of the towers, and others from the platform to the cliffs below, the peculiar circumstances of this bridge imposing no restrictions as to headway.[1]

It remains to be seen, how far the general arrangement of the chains and rods, considered simply, and apart from the question of the stiffness of the roadway, may be so modified, as to reduce some of the disturbances arising from the causes already adverted to. One modification has been proposed, in which four main chains are employed. Each chain rises from the platform level, at one tower, to the summit of the opposite tower, so as to resemble one half of a main chain, for a bridge of double the span.

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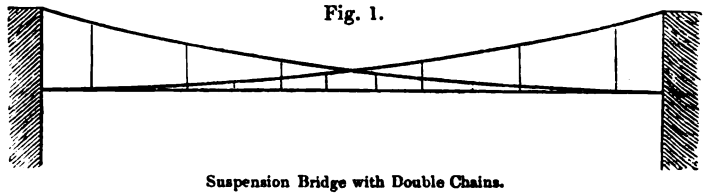
[1] *Vide* "Memoir of the Niagara Falls Suspension Bridge." By John Roebling, C.E., of the United States. Weale, 1856.

The pair of chains, on each side of the platform, thus cross half way, and they may be connected together at the points where they cross. The suspension rods are hung alternately from one chain and the other. This plan offers certain advantages in correcting the disturbances produced in the chains by irregular loading; the fixing down of the lower ends of the chains to the towers will also greatly reduce the liability to swing. Such a bridge will, however, require an enormous amount of material: as much, in fact, as an ordinary suspension bridge of double the span and the same maximum load, the height of the towers being equal in the two cases. Thus, the metal required for this bridge will be more than enough to construct two ordinary bridges of the same span, and having towers only half the height. This mode of suspension is shown in Fig. 1.

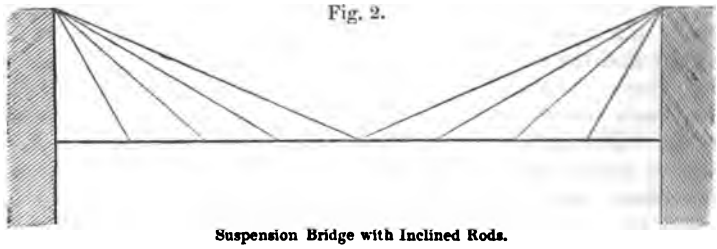
Fig. 1.



Suspension Bridge with Double Chains.

More important advantages are secured by arrangements, in which the suspension rods are sloping instead of being vertical.

Fig. 2.



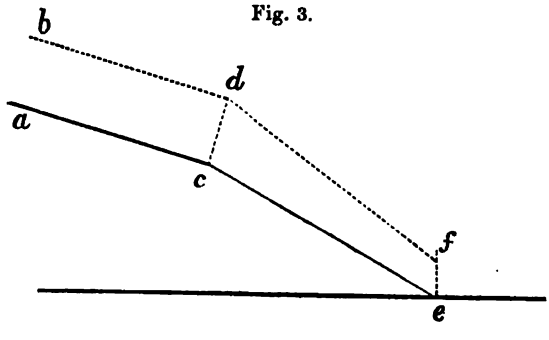
Suspension Bridge with Inclined Rods.

Fig. 2 represents the common direct suspension by rods alone, which may be regarded as the basis of all systems having inclined rods. In this method the absence of chains entirely removes the liability to deflections and undulations. But the great length of the more central rods, as well as the danger of some rods working loose and throwing the whole duty on the rest, constitute serious objections against the direct mode of suspension.

It thus seems necessary to revert to the chain, as the only means of insuring the constant, equable adjustment of the varying strains, at the same time that it materially shortens the central rods. The combination of a chain with slanting rods

approaches the character of direct suspension, and although not absolutely free from undulations, it is far less liable to them than the usual arrangement. This appears from the consideration, that while the vertical rod communicates any disturbing impulse in a direction approaching that of the radius of the curve, so as to cause extreme deflection and the greatest amount of agitation, the slanting rod transmits its impulses more nearly in the direction of the curve of the chain, the tension of which it increases, without causing much depression, so as to transmit the shock almost immediately to the pier. Again, if the chain be drawn up, or deflected, by any cause, the radiating action of the inclined rod greatly reduces the disturbance caused in the platform. Fig. 3 exhibits the case of a rod so inclined as to extend over half the subtangent of the curve of the main chain, the curve being a parabola. In this instance, as is shown by the calculations in the

Fig. 3.



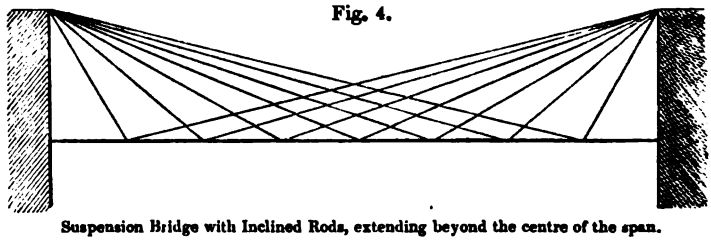
MS. Appendix to this Paper, the vertical displacement of the platform is little more than half that of the chain. Another advantage, attending the use of sloping rods, is the economy which it renders practicable in the chain. It is true, that the weight of the rods will be very much greater, than in the common forms of bridge, but this will be much more than compensated by the reduction in the chains, which may be considerably tapered, as they recede from the towers, and material may thus be saved in a much greater degree than can be effected in bridges with vertical rods.

It must, however, be objected to the method of suspending by sloping rods, that the load on the roadway will subject the platform to horizontal strains, resembling those which it produces in the chains. Whether these strains be regarded as extensile, or compressive, the result must be, that the stability of the bridge requires a platform strong enough to sustain either extensile strains, similar to those borne by the lower section of a girder,

of which the middle depth is equal to the deflection of the chain, or else compressive strains, similar to those borne by the upper section of such a girder. Thus the roadway becomes a heavy item in the cost of the bridge, which shares in a great degree the character of a girder suspended from chains.

In seeking a mode of removing this disadvantage, let the direct mode of suspension be again reverted to. Fig. 4 exhibits a mode of direct suspension, in which the system of rods from either pier, instead of stopping at the half span, extends beyond it, to the opposite end of the platform. Thus, each point is supported by a pair of rods converging from the opposite towers, and the horizontal strains being neutralised, the platform is exempted from all duty, excepting its natural office of carrying the load.

Fig. 4.



Suspension Bridge with Inclined Rods, extending beyond the centre of the span.

But the objections made to the common direct suspension will apply with double force to the arrangement now suggested, since twice as many rods must be employed, and most of them will require to be of enormous length, some rods being even longer than the span of the bridge. These considerations show the employment of chains to be absolutely necessary.

The course of inquiry thus naturally leads to an arrangement, in which a double set of convergent rods is attached to a double set of chains, the rods meeting the chains at very acute angles. Each chain will extend from the summit of a tower, to the platform-level at its opposite extremity, and the curves of the chains will cross at the half-span. It is not, however, essential that any chain should extend the whole distance from tower to tower, provided its lower end can be well secured by other means.

A bridge constructed on this principle may be distinguished as a convergent suspension bridge. If the curve of the chains be such as to insure equilibrium, an increased load, equally distributed over the platform, tends merely to render the whole arrangement tighter and firmer, without causing either deflection, or a strain on the platform. It may, however, conduce to economy, to make use, to a certain degree, of the capability of the platform to sustain tension, if by so doing a saving can be effected in the strength of the chains.

The convergent bridge, without requiring a rigid platform, shares all the advantages of bridges with a single set of inclined rods, besides having some peculiar to itself. If a weight impinge on any point of suspension, the disturbance will be shared by two chains instead of one, and the effect will be proportionately diminished, while the fixing down of the lower extremity of each chain, by checking the lateral movement, will reduce the undulations. The fixing down of the chain has also a great tendency to lessen the danger of any transverse swing.

The determination of the inclinations for the rods and the curves for the chains, calculated to insure equilibrium in a convergent bridge, presents a problem of some complexity and admitting of a great variety of solutions. The simplest solution leads to the forms of bridge exhibited in Figs. 5 and 6. It is, however, possible, that other solutions might be obtained which, although not so simple, would enable bridges to be constructed for great spans, at less cost of material, than the designs now exhibited would require. The nature of the problem is shown in the MS. Appendix, and this question appears well worthy of the attention of engineers.

Fig. 5 exhibits a convergent bridge on the arrangement that will here be called Design No. 1. O Q, O′ Q′, are the main chains, hanging in arcs of parabolas, of which the vertices are at O, O′, at which points, as well as at Q, Q′, they are firmly fixed: the attachments at Q, Q′ being to stay chains, and those at O, O′ to bolts built into the towers. The inclination of any suspension rod, as P Z is such, that the distance of Z from the opposite tower O Q′ is three-quarters the distance of P from the same tower. Two portions O V′, V O′ of the platform, each equal to a fourth of the span, are sustained by rods, one out of every pair of which is attached to a main chain, and the other to the pier. The rods attached to the pier are fixed in the same positions as if they were carried up to a continuation of the main chains, beyond the face lines of the towers. The deflection of each chain is equal to one-eighth of the span.

This mode of suspension requires, for ordinary spans, about the same amount of metal, in the rods and the chains, as a common suspension bridge, of which the deflection is one-thirteenth of the span: but as the span increases, the convergent design, No. 1, becomes more and more costly, in comparison with the ordinary bridge.

To economise material, it is requisite to reduce the tension of the chains, by allowing them more flexure. This may be secured by the Design No. 2, Fig. 6. In this design, the portions V′ O, O′ V of the platform, each equal to one-fifth of the span, are supported by rods radiating from the tops of the piers, on the direct

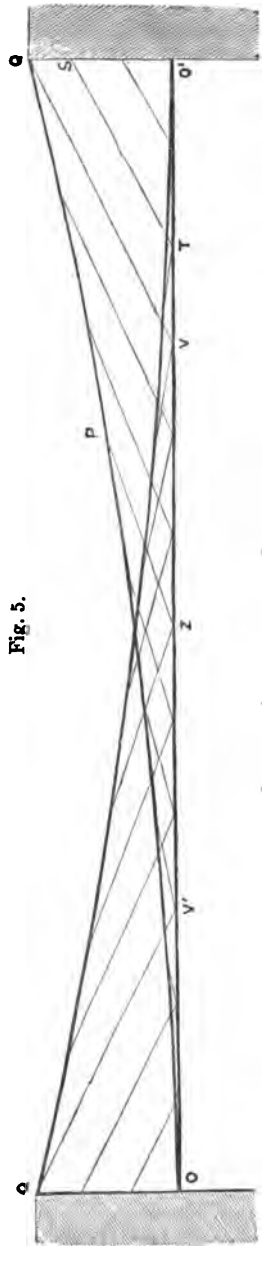


Fig. 5. Convergent Suspension Bridge—Design No. 1.

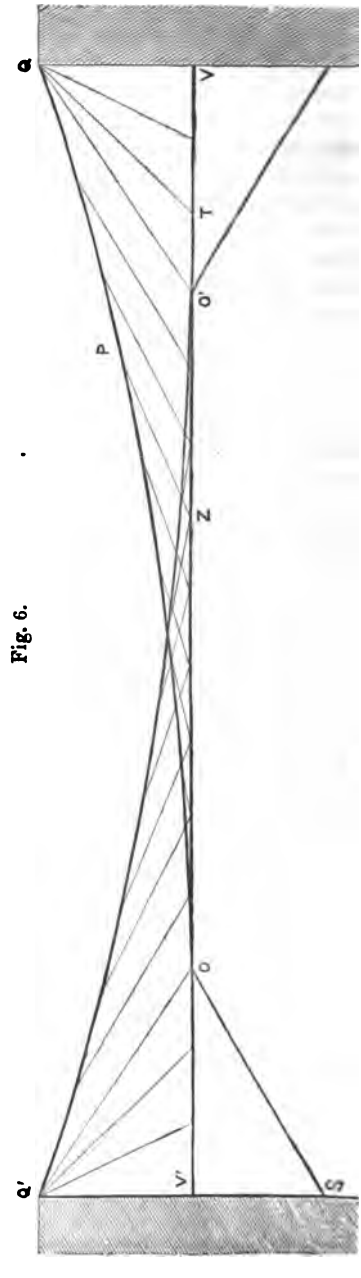
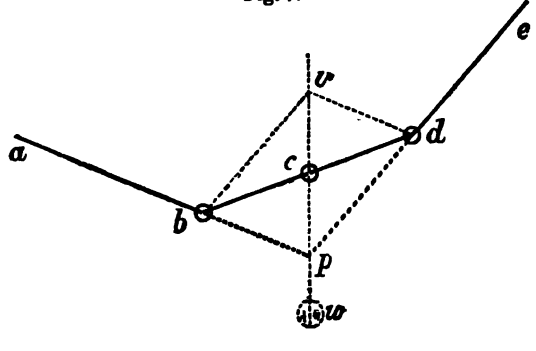


Fig. 6. Convergent Suspension Bridge—Design No. 2.

suspension principle. The points O, O′ are the vertices of parabolas O Q, O′ Q′ in which the main chains are hung, the convergent rods having the same inclinations as in Design No. 1. Under-stays O S, O′ S′ pass from the lower extremities of the chains to points S, S′, where they are attached to bolts built into the piers, at a depth below the platform equal to one-tenth of the span. The object of these stays is to guard against the points O, O′ being disturbed by any agitation of the chains, as well as to assist in sustaining the horizontal strain caused by the tension of the chains, when the portions V′ O′, O′ V of the roadway are not heavily loaded. When the loads on these portions of the platform are very heavy, the horizontal strains caused at O, and O′ may exceed the opposing tension of the main chains. In such cases the excess of strain acts mainly on the portion O O′ of the platform bearer, which thus takes the place of a tie-beam. The height above the platform of the towers of Design No. 2, Fig. 6, is two-fifteenths of the span. The increased curvature allowed to the chains effects great economy in this form of bridge, which requires considerably less metal for its construction, than an ordinary bridge, having a deflection equal to one-thirteenth of the span, and capable of sustaining an equal amount of weight, before breaking. To diminish the danger of transverse swing, it is proposed to arrange the chains and rods in battering planes, converging slightly as they approach the platform level.

The proper adjustment of the strains borne by each rod, in every pair, claims especial consideration. This end can be secured by the use of a self-adjusting lever, as shown by *b c d* in Fig. 7, the positions of the convergent rods being indicated by the lines *a b*, *d e*, and the point of suspension in the platform hanging from the fulcrum *c*.

Fig. 7.



The position of the lever being determined on the principles

explained in the MS. Appendix, it will remain in stable equilibrium, so long as each rod bears its proper share of strain: but if, through a disturbance of the chains, one rod is tightened, and the other rendered slack, the lever will change its position, so as to throw less weight on the slackened chain, and more weight on the chain which is drawn up, thus tending to check the disturbance, at the same time that the play, thus admitted, greatly diminishes the displacement of the platform. When the disturbing cause ceases to operate, the lever will resume its position of equilibrium. These levers must not be considered as indispensable.

The fourth cause of disturbance, mentioned at the commencement of this Paper, arises from the weight of the chains, and is common to all suspension bridges, although not existing in equal degrees in the various designs, nor in the same design for different spans. While the conditions of suspension usually require a parabola as the curve of the main chains, the chains would, if left to themselves, assume catenaries, or if tapering, curves still further removed from the proper lines. As the span is augmented, the appreciable difference between the normal and the natural curve increases, and the mass of the chains rapidly becomes so considerable, in proportion to the suspended load, that it seems no longer safe to neglect the adjustment of the conflicting strains. By a rigid platform of sufficient strength, the main chains might be kept permanently warped from their natural curves. For large spans, however, this would require much weight, as well as strength, in the platform; and in imposing on it this task, much of the strength must be expended that would otherwise be available for other duties. On the other hand, if the platform is not sufficiently stiff, it will be constantly distorted from its true line, when the maximum load is not on the bridge, unless the chains can be caused spontaneously to assume the curve required by the conditions of suspension.

This end can be attained, by ballasting the lower portions of the main chains. A formula is given in the MS. Appendix, for determining the gross sectional weight at every part of a chain, so as to insure its equilibrium in any assigned curve. By these means the steadiness of the chains will be increased, and the bridge be entirely freed from disturbances of the nature referred to.

It may be objected to this expedient, that adding to the weight of the chains causes more strain, and thus renders greater strength necessary. It is, however, clear, that the measure of strength will always be the maximum load; and the stiffness of the roadway, when weighted with the maximum load, would throw vertical pressures on the chains of the same nature, that it is here proposed to apply constantly by means of ballast.

It may, therefore, be inferred, that while the weighting of the chains would cause much less strength to be requisite in the platform, it would not demand any great increase of metal in the chains.

In order to compare the cost in material of convergent bridges and bridges with vertical rods, Table No. 1 (Appendix p. 470) has been computed from formulæ, the proofs of which are given in the MS. Appendix. It is assumed, in these formulæ, that the chains are so tapered as to be of equal strength throughout. This, though not usual in the common suspension bridge with vertical rods, would nevertheless effect an economy of material, and therefore the results are more fairly comparative, than if the chains were taken as of uniform section. Taking the breaking strain of iron at 25 tons per square inch, this Table exhibits the tonnage of iron in rods and chains, for every hundred feet span, up to one thousand feet; the breaking weight being taken at 12 tons for every foot of span, equally distributed over the surface of the roadway, exclusive of the effect of the weight of the chains. No allowance is made for bolts, overlap of links, or stay chains, the object of the Table being simply to facilitate comparison as to cost. The amount of metal is, in every case, divided into that required to support the load, and the metal that has to be added to the chains, to enable them to sustain their own weight, in addition to the greatest load. The first item increases as the square of the span, and the second item a little more rapidly than the cube of the span. As the span approaches certain limits, depending on the strength and weight of the metal employed, it becomes a question of more importance how to sustain the chains, than how to support the load. Four forms of bridge are selected for comparison in this Table; namely:—the two designs for convergent rods; a bridge with vertical rods, having the main chains in parabolas, with a deflection equal to one-thirteenth of the span; and a bridge with vertical rods and intersecting main chains, having a deflection equal to one-eighth of the span. The weights of wrought iron tubular girders up to 300 feet span, exclusive of rivets and joints, are also given, the depth of girder in the middle being from one-fifteenth to one-thirteenth of the span, and the breaking load the same as in the other bridges, inclusive, however, of the weights of the girders themselves.

In order to exhibit the effects of employing a material stronger in proportion to its weight than iron, Table No. 2 (Appendix p. 471) is computed for bridges of the same dimensions and breaking weights, showing the estimated tonnage of steel for chains and rods, taking the breaking strain of steel at 60 tons per square inch. It will be seen, from an examination of the two Tables, that when the stronger metal is employed, the convergent suspen-

sion compares more favourably, in point of economy, with the vertical suspension, than when wrought iron is the material selected for the chains and rods.

The proofs of the formulæ, from which the Tables referred to are computed, as well as the analysis by which the designs for convergent suspension, now explained, were arrived at, being unsuited for insertion in a Paper of this nature, are given in detail in the MS. Appendix.

The fifth source of disturbance adverted to, is that which exists in suspension bridges of more than one bay. If two adjacent bays are unequally loaded, a strain will result, tending to overthrow the middle tower, unless a continuous main chain is adopted, with sufficient play, where it rests on the tower, to allow the unequal tensions to adjust themselves. But as this adjustment will be accompanied by the sinking of the roadway bearing the heavy load, and the drawing up of the more lightly loaded platform of the other bay, a new source of derangement arises, which, in the case of heavy railway traffic, assumes a formidable character.

An inverted system of chains and rods below the roadway, presenting the appearance of arches springing from the lower parts of the piers, might be adopted, in cases where the extent of headway admitted of such an arrangement, so as effectually to prevent, or to reduce, within safe limits, the drawing up of the platform. In large spans, the additional cost of the inverted chains would be far less than would attend the substituting, for two bays, one of more than twice the span. But it is now proposed, not so much to inquire into the means of combating the danger, as to trace how far the cause of disturbance, existing in the inequality of tension induced in the main chains of adjacent bays, may be modified by the mode of suspension. With this view Table No. 3 (Appendix p. 472) is given, showing the strains in tons, at the highest point of the main chain, for the greatest and least loads in different bridges, and exhibiting the ratio of the greatest to the least tension. The least load is taken at $\frac{3}{4}$ of a ton for every foot of span, which is assumed as the weight of the platform alone; and the greatest load is taken at $2\frac{3}{4}$ tons per foot of span. The bridges selected for examination are, an ordinary suspension bridge with vertical rods, and the two designs for bridges with convergent rods, of which the weights are given in Table No. 1. It will appear, on inspection, that in every case the extreme inequalities of tension, in the convergent bridges, are somewhat less than in the vertical-rod bridge of the same span; but in the convergent design, No. 1, Fig. 4, the superiority, in this respect, becomes remarkable, as the span increases.

Having thus briefly glanced at the chief causes of instability in

suspension bridges, with such suggestions for their remedy as seem most feasible, the Authors hope that, however imperfectly the subject may have been treated, it may give rise to discussion and investigation, calculated to elucidate a subject of acknowledged difficulty, but of great practical importance.

The Paper is accompanied by a series of Diagrams from which Figs. 1 to 7 are compiled; and by a MS. Appendix giving the formulæ and calculations referred to in the Paper.

[APPENDIX.

APPENDIX.

Table No. 1.

Weight of Wrought Iron, in chains and rods, required for different Suspension Bridges;—the breaking-weight being taken at 12 tons per lineal foot, equally distributed over the platform; and the breaking-weight of wrought iron at 25 tons per square inch.

	Spans in Feet.									
	100	200	300	400	500	600	700	800	900	1000
Common Suspension Bridge.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Deflection = $\frac{1}{12}$ span.										
To support load .	12·17	49	110	195	304	438	596	779	986	1217
To support chains	0·13	1	4	8	17	29	47	71	102	142
Total . .	12·30	50	114	203	321	467	643	850	1088	1359
Suspension Bridge, with crossed chains and vertical rods.										
Deflection = $\frac{1}{4}$ span.										
To support load .	29·50	118	266	472	738	1062	1446	1888	2390	2950
To support chains	0·76	9	22	53	106	189	309	475	698	990
Total . .	30·26	127	288	525	844	1251	1755	2363	3088	3940
Convergent Bridge, No. 1.										
To support load .	11·4	46	103	183	286	412	560	732	927	1144
To support chains	0·4	4	12	30	60	106	173	267	393	557
Total . .	11·8	50	115	213	346	518	733	999	1320	1701
Convergent Bridge, No. 2										
To support load .	7·7	31	69	123	192	276	376	491	622	768
To support chains	0·2	2	6	15	29	51	83	126	183	256
Total . .	7·9	33	75	138	221	327	459	617	805	1024
Wrought-iron girder	40	177	398	..	..	..	..	..	..	..

TABLE No. 2.

WEIGHTS (in tons) of Steel required for chains and rods in different forms of Suspension Bridges, the breaking strain being taken at 60 tons per square inch.

	Spans in Feet.									
	100	200	300	400	500	600	700	800	900	1000
Common Suspension Bridge.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Deflection = $\frac{1}{12}$ span.										
To support load .	5·17	20·7	47	83	129	186	254	331	419	518
To support chains	0·02	0·2	1	2	3	5	8	12	17	24
Total . .	5·19	20·9	48	85	132	191	262	343	436	542
Suspension Bridge, with crossed chains and vertical rods.										
Deflection = $\frac{1}{8}$ span.										
To support load .	12·55	50·2	113	201	314	452	615	803	1016	1255
To support chains	0·14	1·1	4	9	18	31	50	75	108	150
Total . .	12·69	51·3	117	210	332	483	665	878	1124	1405
Convergent Bridge, No. 1.										
Deflection = $\frac{1}{8}$ span.										
To support load .	4·9	19·5	44	78	122	175	238	311	394	487
To support chains	0·1	0·6	2	5	10	17	28	42	61	84
Total . .	5·0	20·1	46	83	132	192	266	353	455	571
Convergent Bridge, No. 2.										
Deflection = $\frac{1}{12}$ span.										
To support load .	3·27	13·1	29	52	82	118	160	209	264	327
To support chains	0·04	0·3	1	3	5	9	14	21	30	42
Total . .	3·31	13·4	30	55	87	127	174	230	294	369

TABLE No. 3.

COMPARATIVE Tensions at highest point of one main chain, for a maximum load of $2\frac{3}{4}$ tons, and a minimum load of $\frac{1}{4}$ths of a ton, per lineal foot, in various forms of Suspension Bridges, for a breaking load of 12 tons per lineal foot.

	Spans in Feet.									
	100	200	300	400	500	600	700	800	900	1000
Suspension Bridge. Deflection = $\frac{1}{12}$ span.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.	Tons.
Maximum load .	457	936	1437	1961	2507	3078	3676	4298	4947	5624
Minimum load .	133	285	462	662	882	1129	1400	1698	2023	2373
Ratio . =	3·4 :1	3·3 :1	3·1 :1	3 : 1	2·8 :1	2·7 :1	2·6 :1	2·5 :1	2·4 :1	2·4 :1
Convergent Bridge, No. 1.										
Maximum load .	338	712	1128	1589	2098	2659	3279	3961	4712	5539
Minimum load .	106	248	432	661	939	1268	1656	2106	2625	3220
Ratio . =	3·2 :1	2·9 :1	2·6 :1	2·4 :1	2·2 :1	2·1 :1	2 :1	1·9 :1	1·8 :1	1·7 :1
Convergent Bridge, No. 2.										
Maximum load .	270	559	868	1198	1550	1925	2325	2750	3203	3684
Minimum load .	81	178	298	439	603	786	997	1233	1494	1786
Ratio . =	3·3 :1	3·1 :1	2·9 :1	2·7 :1	2·6 :1	2·4 :1	2·3 :1	2·2 :1	2·1 :1	2·1 :1

NOTE.—This Table shows the inequality of tension produced in the main chains, on opposite sides of a tower, standing between a fully loaded and an unloaded bay.

Mr. R. STEPHENSON, M.P.,—President,—said, this Paper touched upon an important point, which had deeply engaged the attention of engineers—the comparison of suspension bridges with those of the girder construction, for use on railways. The Authors had evidently given considerable attention to the subject, and he hoped the Paper would lead to an interesting discussion.

Mr. LUKIN said, in the Figures given in the Paper, the stay chains were omitted, but they must be supposed to exist as in ordinary structures of the same kind. In referring to the bridge with convergent rods, Fig. 4, he mentioned the fact of there being one on a similar principle at Harper's Ferry, in America, in which, however, the use of stay chains was obviated, by the employment of a tube between the towers, somewhat like that in the Chepstow Bridge, designed by Mr. Brunel. The Harper's Ferry Bridge was an instance of the disadvantage of employing rods, without chains; for whereas the longest rod was 114 feet, in the arrangement advocated, in which chains were used, the longest rod for the same span (150 feet) would scarcely exceed one-fourth of that length. There would also be much less "sagging" of the rods, when main chains were used, than when the direct rods alone were employed. He thought one great object of the chain was to tighten the suspension rods, which had a tendency, by "sagging" down, to draw up the platform. Indeed, in those suspension bridges, having a girder platform, it might be a question, whether the girder should not be chiefly considered as resisting the upward strain, caused by the tension of the chains and rods, and therefore causing stability by that means. It had been endeavoured, as far as possible, to remove the undulations affecting the platform and chains of a common suspension bridge, and by the proposed arrangement to keep the bridge in its normal position. A girder platform, rigid enough to restrain the disturbances of the main chains, must be strong enough to carry the weight which caused that disturbance. He thought the best mode of obtaining stability was by suspension, rather than by trusting to any rigidity of the platform. In fact, he considered the duty of the platform to be, simply to carry and distribute the weight, and that all tension should, as much as possible, be thrown on the chains and rods. The platform of railway bridges might consist merely of cross sleepers, suspended from the rods, with longitudinal timbers to carry the rails, forming a skeleton platform not likely to be acted on by the wind. If a girder was used, it should be sufficiently stiff to distribute the weight, or pressure, over at least one-third of the span, so as to throw less weight upon any particular rod. The Niagara Falls Suspension Bridge had two platforms, one over the other, braced together so as to form a deep truss. He did not know how far such a girder would support the load, independently of the

chains, or what sustaining power it had; but besides the chains, and the vertical rods, there were direct rods, from the top of the tower to one-third of the span, and also stay rods underneath. One-third of the platform, at each end, was thus supported, independently of the chains, an arrangement which no doubt had the effect of preventing a great deal of undulation. As had been mentioned, rods forming acute angles with the platform threw the strains very much towards the tower, without exercising any great amount of vertical strain. In Fig. 3 a portion of a main chain was shown in two positions, so as to prove that when the chain rose, or fell, the point of the platform to which the rod was attached rose, or fell, about half the distance. This was one of the advantages of the inclined rods. When he made experiments upon a model, it was evident, that it was altogether so much stiffer, in proportion, than would be the case with a real bridge, that he had merely noticed general results; but if the load caused a considerable deflection at any one point, without causing a corresponding elevation at another point, so far it might be argued, that there would be no material undulation. The model was for a span of 240 feet, at a scale of a quarter of an inch to a foot. When a truck loaded with 7 lbs. or 8 lbs. was sent across the loaded bridge, at various speeds, he found that a deflection at one point did not produce an elevation at any other point; there was, in short, no undulation. The platform sank gradually from the tower: and the whole length was deflected into one gradual equable curve. But as he had before said, he did not desire to draw any positive conclusions from such experiments.

Mr. CONDER remarked, that the Tables 1 and 2 (Appendix pp. 470, 471) might be found useful, as showing the economy, comparatively speaking, of different forms of suspension bridges. But though the actual weights of girder bridges might be from 40 tons to 400 tons, for similar breaking weights, yet that was not a fair criterion, in point of economy, because from 50 to 75 per cent. must be added to the weight of the suspension bridge, for the stay chains. The weights of girder bridges were put down, merely to afford some data for comparison. Mr. Lukin and himself were anxious that it should not be understood, that they did away with the stiffness of the platform. The vertical stiffness of the platform was important, as distributing the load over the whole, or the greater portion, of the chains, as well as for resisting the effects of gales. The way in which the chains tore up the roadway, in violent storms, was well known, from the instances of the bridge over the Menai Straits, and the Wheeling Bridge in America. On comparing the superficies which the platform exposed to the action of the wind, with that which was exposed by the chains, it became evident, that the disturbance naturally began

in the platform, as undergoing the most pressure. Although the platform might disturb the chains, the chains could not steady the platform. Therefore, it was important, that the platform should be sufficiently stiff to withstand the pressure of the heaviest gales. There was, however, another danger to be guarded against, resulting from the mobility of the chains, which precluded the stiffness of the platform being increased beyond certain limits; since it seemed very undesirable to connect a perfectly rigid structure with a mobile chain. In the case of the Britannia Bridge, it was decided not to do so; but when there were two platforms, as in the Niagara Bridge, the intervening depth not only admitted of a deep trussing, but also afforded room for many dead points, to which to fix the chain, so that it ceased to be a mobile structure. It became more like an arch, with the spandrils reversed. The investigation had simply been into the best mode of rendering the chains steady in themselves, and as little liable to undulations as possible. If there was danger from too stiff a platform, this danger was lessened, in proportion as the chains were steady. At the same time, the steadier the chains were rendered, the less stiffness was required in the platform. Thus, the first point to settle related to the chains: having decided this, it could afterwards be considered what to do with the platform. In speaking of multiple spans, he might mention the case of the tube, as applied in the bridges at Chepstow, at Saltash, and some other places. By the use of the tube, both the continuous chain and the stay chain were dispensed with. The question might arise, how far it was economical to use stay chains, notwithstanding the acknowledged safety of the tube. The plan of using inverted chains below the platform, to prevent its being pulled up by unequal loading, in multiple spans, was adopted in the suspension bridges, designed by the late Sir Isambard Brunel, in the Isle of Bourbon. The convergent arrangement did away with the horizontal strains, which the action of a single set of slanting rods threw on the platform. These strains resembled those in a girder, in which the depth was the same as the rise of the chains. In support of this, he might adduce the remarks made by Mr. Dredge, in his pamphlet[1] containing the calculations of a bridge of 500 feet span, with a load of 625 tons. The rise of the chains was 41 feet 10 inches,—about one-twelfth of the clear span. With a load of 625 tons upon the platform, Mr. Dredge considered there was a horizontal strain upon the platform of 954 tons, or 50 per cent. more than the load. This was within a few tons of the strain that the same load would occasion, in the top

[1] *Vide* "Description of Suspension Bridges on Dredge's Patent Taper Principle," pp. 10, 20. Edinburgh. Printed by W. Burness, 1851.

or bottom flange of a lattice girder of 500 feet span, and 41 feet 10 inches rise. This horizontal strain rendered it necessary to give a large sectional area to the platform. Thus, in the case adduced, the platform (if of iron) ought to have 190 inches sectional area, and would thus weigh more than 140 tons. The convergent rods removed this necessity for a heavy platform; and any vertical stiffness, that would be required, might be secured in a light platform, by giving a sufficient depth of truss.

It might be objected to long slanting suspension rods, that they were apt to "sag." A "sagging" bar, however, had nothing in common with a catenary, except the fact of its not being straight. It was quite clear, that the facility of acquiring and transmitting undulatory motion, which was the main cause of the unsteadiness of suspension bridges, did not exist in a rod, in the same sense that it did in a chain.

Mr. P. W. BARLOW said, that as engineer of the Londonderry and Enniskillen and Londonderry and Coleraine Railways, he had recently received instructions to design a bridge for crossing the river Foyle, at Londonderry. It was proposed, that the bridge should have two platforms, the upper one to carry the ordinary road traffic, and the lower one to support the railway carriages drawn by horses, the connection with the two lines being by means of turn-tables. That object, he believed, could be best effected by a suspension girder bridge. The chief point to be aimed at, was to prevent the horizontal and vertical oscillation, common to ordinary suspension bridges. This he had endeavoured to accomplish in the proposed structure. The upper platform was formed of wrought-iron plates, laid horizontally, and connected with the lower platform by lattice work. The chains were carried down to the lower platform, and were united to the girder throughout, so that in one-half of the bridge, in the centre, the chains performed the double duty of supporting the bridge and contributing to its stiffness. A cast-iron tower, 100 feet in height, and having an opening 36 feet in width, afforded a passage for ships, which was required by the Admiralty authorities. This plan had been approved by Sir William Cubitt, M. Inst. C. E., consulting engineer to the Bridge Commissioners, and he had considered that it was the best way of meeting the case.

It appeared to Mr. Barlow, that the modification, alluded to in the Paper, of having two chains on each side of the roadway, rising from the platform level, at one tower, to the summit of the other tower, and crossing each other in the centre of the span, only attained stiffness by doubling the quantity of iron used, but he doubted whether it would preserve rigidity under vertical pressure. Mr. Barlow disagreed with the assertion, which was unsupported by a single fact, that a girder could not be applied to

a flexible chain. There was no more difficulty in rendering a flexible chain rigid than an arch, which, being usually constructed with solid spandrils, was supposed to be, in principle, more rigid; whilst chain bridges were usually made with light platforms, with no attempt at rigidity. The only case, he remembered, of a rigid iron platform for a suspension bridge, was that at Inverness, where the parapet was made of wrought iron plates 3 feet 6 inches in depth. This bridge had been tested by a locomotive being drawn across, by fourteen horses, at a trot. Relative to that test, the following report by the late Mr. Rendel, M. Inst. C. E., dated 11th September, 1855, had been made:—

"When the locomotive passed over, I placed Coates (the foreman) at the end of the longitudinal girders, where he noticed a slight bend, not $\frac{1}{4}$ of an inch, opposite the engine. I stood on the centre of the bridge and narrowly watched the handrail, as the locomotive passed; the deflection appeared to me less than Coates observed. The shake, or vibration, although the bridge was half full of people, rushing by as the horses trotted over, was less than is perceptible when a single carriage goes over."

Mr. Edwin Clark remarked, that the proposed modification in the arrangement of the chains, did not affect the general principle of construction, nor was the comparison with the chains in an arch an admissible argument. On the one hand, the arch was, it was true, a series of links in stable equilibrium, but without any motion whatever. In the other case, the suspension bridge was a series of links connected by pins, in such a manner that the whole strength of the structure depended upon its instability. No such system could resemble an ordinary arch. The oscillation arose from the play of the chains at the joints of the links, and so long as the chains were of considerable length, however they might cross each other, or in whatever direction they might be placed, this oscillation would exist. A rigid suspension chain must consist of two links alone. The pin that joined them would then be a fixed point, and if such a structure could be made, they would have a perfectly rigid bridge. Unfortunately, the links themselves, when of any great length, became suspension bridges; their length made them catenaries, and if they were connected at the points where they crossed each other, a bad trellis girder merely would be formed, in which each bar was curved, and in a state of unstable equilibrium. The real difficulty had not been touched upon. It had been attempted to give rigidity to suspension bridges, by making the roadway rigid; but the simultaneous expansion of the chain and of the girder, was incompatible with the preservation of a horizontal platform. In the Britannia Tubular Bridge, with a span of 460 feet, under the ordinary temperature of this climate, the vertical rise and fall of a chain at the centre would be through a space of 6 or 7 inches, whilst the horizontal motion of the roadway itself would

be only through a space of 2 or 3 inches. Yet the roadway must necessarily be capable of rising and falling with the chain, through the space of 6 or 7 inches. If the roadway was so rigid that it did not follow this motion of the chain, it would evidently, at times, be doing all the work, and at other times nothing at all; whilst any partially flexible roadway, sufficiently rigid for railway traffic, must necessarily be of such great independent strength, that the addition of the material in the chain would be employed to greater advantage in converting it into a simple rigid girder. Two such incompatible systems could not be combined, either with economy, or advantage, nor could they be made, practically, to act in unison. In the example given of a locomotive being taken over such a bridge at a trot, he did not think it was a case in point; and it was to be remarked, that the person who took an account of the deflection was upon the bridge, not the most favourable point for making such observations. With regard to the Niagara Bridge, he had reasons for believing, that it was not efficient for the purposes for which it was intended. The deflection was so great, that the trains passed over at a very slow pace, and the passengers frequently alighted at one end and walked to the other, where they again entered the train. The effect of the slow speed, which was rendered indispensable by the deflection of the bridge, had been greatly to impede the traffic. He understood, that it was in contemplation to erect some other bridge at that place.

Mr. BARLOW remarked, that in a communication he had received from Mr. Brackstone Baker, the Secretary to the Great Western Railway Company of Canada, he stated, "I never heard, before you mentioned it, that it was our intention, or anybody's intention, to build another suspension bridge; but its great success may perhaps induce railway men to build similar bridges elsewhere. Mr. Hodges, an engineer of the Grand Trunk Line, did, indeed, once make a model of a tubular bridge, to replace our suspension bridge, when it gives way."

Mr. R. STEPHENSON, M.P., President, remarked, that the discussion went to show, that difference of opinion existed on this subject, and he hoped it would not be allowed to rest where it was. A further communication upon it had been promised, and he trusted, by the end of the next session, they would be able to reconcile these differences, and to reduce the question to a simple form.

May 26, 1857.

The Session was concluded by a CONVERSAZIONE, at which the President received the Members of the Institution, and a numerous circle of distinguished visitors. The rooms were decorated with many choice works of art, and there was also exhibited a large and interesting collection of mechanical models.

MANBY TESTIMONIAL.

THE Members of the INSTITUTION OF CIVIL ENGINEERS had, for some time, entertained the intention of demonstrating, in an appropriate manner, their personal esteem for Mr. Charles Manby, with their sense of the valuable services rendered to them individually and collectively, and at the same time of acknowledging the ability with which he had, during eighteen years, performed the duties of Secretary to the Society. Advantage was taken of the opportunity of his retiring from the post of paid Secretary, to carry this intention into effect; a Committee was formed, composed of Messrs. R. Stephenson, M.P., President; G. P. Bidder, I. K. Brunel, J. Hawkshaw, and J. Locke, M.P., Vice-Presidents; W. G. Armstrong, J. Cubitt, J. E. Errington, J. Fowler, C. H. Gregory, T. Hawksley, J. R. McClean, J. S. Russell, J. Whitworth, and N. Wood, Members of Council; R. W. Kennard and Sir R. M. Stephenson, Associates of Council; J. Walker, J. Field, Sir J. Rennie, Sir W. Cubitt, and J. Simpson, Past-Presidents; with Messrs. T. E. Blackwell, T. R. Crampton, W. T. Doyne, G. W. Hemans, R. Mallet, J. E. M'Connell, G. Peel, J. Samuel, and W. Simpson, Members; and Messrs. J. G. Appold, C. Cammell, J. Freeman, J. Hamilton, jun., W. A. Matthews, W. Piper, J. Allen Ransome, H. G. Robinson, W. Swann, G. F. White, and T. H. Wyatt, Associates.

In a very short period a sum exceeding Two Thousand Pounds was subscribed, with which it was determined to purchase a fitting Testimonial, and to present the balance in cash. The ceremony of presentation took place in the Theatre of the Institution, on Saturday, the 23rd of May, in the presence of a large assemblage of the Members and of Mr. Manby's private friends, who had been permitted to join in the tribute to his merit.

Mr. ROBERT STEPHENSON, M.P., the President of the Institution, took the Chair, and called upon Mr. Bidder, as Treasurer of the Fund, to give the result of the exertions of the Committee.

Mr. BIDDER, V.P., explained that, owing to the eagerness with which their call was responded to, the duties of the Committee had been comparatively light. The amounts subscribed varied from half a-guinea to one hundred pounds; and those who had contributed the latter sums had done so as cheerfully as those whose means only permitted them to offer the smaller amount. Up to the present time there had been received £2,019. 10*s*., from 417 subscribers, of whom 358 were Members of the Institution, and 59

were the private friends of Mr. Manby[1]; but as many more subscriptions had been announced, the accounts would not be finally closed until the publication of the accounts and of the list of the contributors to the Testimonial. It had afforded him great gratification to aid in this demonstration, for as a very early member of the Institution, he well knew the arduous duties of the Secretary, and he now bore willing testimony to the able and kind manner in which those duties had been performed.

Mr. ROBERT STEPHENSON, President, said the object of the Meeting was well known; Mr. Manby having,—after eighteen years' service,—resigned the position of paid Secretary, it had been resolved to offer to him a testimony of the respect and esteem in which he was held, and in doing this he would make a few brief observations, on the circumstances under which Mr. Manby had become connected with the Institution, the duties he had performed, and the services he had rendered. After the usual struggles and vicissitudes, the young Society, although very ably directed by Mr. Thomas Webster, had scarcely established itself among the scientific bodies of the Metropolis. The Minutes of its Proceedings were but meagrely reported, and its Transactions were scarcely known beyond the Members themselves. From the time, however, when Mr. Manby undertook the duties of Secretary, new vigour was infused into all their proceedings, the number of Members increased, the character of the Papers improved, and the care bestowed on the editing and publication, eventually rendered the record of the proceedings a most useful text-book for the Profession. Mr. Manby's sphere of usefulness was not, however, confined to the performance of his official duties, for he was ever ready to give advice to the younger Members, and to afford aid to the senior Members, from his well-stored mind, in reference to every department of Engineering, as well as in a variety of ways, rendered more pleasing by the alacrity and cheerfulness with which the friendly offices were performed. The value of the information afforded was enhanced by its accuracy, which was to some extent to be attributed to the practical foundation of his professional education, the early portion of his life having been spent in the workshop, as a mechanical engineer, at the period when the profession was beginning to assume its present importance. In some degree, therefore, Mr. Manby lost the official character of Secretary, and became the friend and companion of the majority of the Members of the Engineering profession.

Addressing Mr. Manby, he then said, "I have been extremely

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[1] At the close of the Testimonial the sum collected amounted to £2,126. 3s. from 464 Subscribers, of whom 404 were Members of the Institution, and 60 were private friends.

brief in my remarks, as I would divest our present proceedings of all stiffness and formality; and it is with great pleasure, Mr. Manby, that in confirmation of what I have said, and of the sympathy felt for your welfare by so large a number of Engineers, I have to present to you, on behalf of the Members of the Institution and of a few private friends, this Testimonial, consisting of a Timepiece and a pair of Candelabra, with the sum of Two Thousand Pounds, and long may you live to enjoy the recollection of the honours of this day."

The Timepiece and Candelabra, supplied by Messrs. Howell and James, appeared to afford general satisfaction by their elegance and the good taste with which they had been selected by the Committee. They bore the following inscription:—

PRESENTED
BY THE MEMBERS OF THE INSTITUTION OF CIVIL ENGINEERS AND A FEW PERSONAL FRIENDS,
WITH THE SUM OF TWO THOUSAND POUNDS,
TO
CHARLES MANBY,
AS A TOKEN OF ESTEEM, AND IN RECOGNITION OF HIS VALUABLE SERVICES,
DURING A PERIOD OF EIGHTEEN YEARS,
AS SECRETARY TO THE INSTITUTION,
MAY, 1857.

To the President's kind address Mr. MANBY, who appeared to be much affected, immediately replied, that it rarely fell to the lot of any one to receive so gratifying a testimony of the esteem of those with whom he was in daily contact, and to have the presentation accompanied by such kindly expressions; if he was previously at a loss how to express his feelings, the difficulty was now increased, and he must crave indulgence if the few words of thanks he could utter, appeared inadequate to the occasion. They must not believe him insensible to their kindness,—it had been so constantly shown, that he should indeed be ungrateful, if it had not made a deep impression; and but for the consciousness of having always endeavoured strenuously to perform his duty, he should feel that his poor services had been much overrated.

His connection with the Institution dated from a period long antecedent to his appointment as Secretary. He had been, he was proud to say, apprenticed at an early age as a practical mechanic, and had been taught to earn his bread by daily toil: he was sent up to London by his late excellent Father, to work upon his contracts at the East and West India Docks, where he was noticed by the late Mr. Rennie, by whom, as also by Mr. Telford the first President of the Institution, he was afforded invaluable opportunities of improvement, and became known to

Messrs. Nimmo, Provis, and Palmer, and to them, as well as to Messrs. Field, Maudslay, Bramah, and Simpson, he was at that early period of his career under great obligation. They had permitted him to attend the meetings of the then infant Society of Engineers, and when his Father intrusted to him the construction of the first pair of Marine Engines with Oscillating Cylinders, and the building of the "Aaron Manby," the first iron steam-ship that ever made a sea voyage, it was to the Institution he resorted for advice in difficulties, and he was happy to record the expression of his gratitude for the aid so kindly and unreservedly afforded to him.

He then rapidly sketched his duties in France, under his Father, erecting the Paris Gasworks, manufacturing marine and other steam-engines and machinery, and building large ironworks, &c.—his subsequent career as a commissioned Officer in the Government service,—his return to England and occupation in the iron works of South Wales,—and his settling in London, when he embraced the earliest opportunity of joining the Institution, at that time presided over by Mr. Walker, and under the able direction of Mr. Thomas Webster, whose exertions, in giving to the still young Society a constitution and good laws, and in attracting to its meetings men of scientific eminence, should ever be gratefully remembered. On an emergency Mr. Manby's aid was sought by Mr. Simpson and Mr. Bramah to perform the Secretarial duties, and eventually, in 1839, he was appointed Secretary. The position was novel for one whose career had hitherto been essentially practical, and he felt the disadvantage of succeeding a Cambridge man, whose pursuits were purely literary and scientific; but again good friends lent a hand, and several literary men and members of the press, who had since attained well-deserved eminence, afforded him invaluable counsel and assistance.

The stirring period of the engineering history of the country was commencing, and it was evident how much good would result from bringing into intimate contact the men of talent and energy, whose professional contests tended somewhat to estrange them from each other. With this object steadily in view and a desire to be useful to all, eventually, after certain necessary changes, which consecutively introduced to the Presidential chair Sir John Rennie, Mr. Field, Sir William Cubitt, the late Mr. Rendel, Mr. Simpson, and Mr. Robert Stephenson, and brought into the Council the well-known names of Bidder, Brunel, Hawkshaw, and Locke, as Vice-Presidents, with Armstrong, Bateman, Errington, Fowler, Gregory, Hawksley, Macneill, May, McClean, Miller, Mylne, Penn, Russell, Sopwith, Taylor, Whitworth, N. Wood, and others, the value of the Institution was recognised, and it became the arena where the men of the day met, and whilst mutually learning to

estimate their several powers, they formed friendships which had tended to most beneficial results, and were imbued with ambition to execute the great works conferring such inestimable benefits on society.

The labour required for obtaining such results was no doubt considerable, but the Council judiciously directed the course, and it had been fortunately successful; the Institution had been extensively useful, and was as well known and respected abroad as at home, for it had been a pleasing duty to Mr. Manby to give a cordial welcome to all Foreign Scientific men, and to obtain for them, through the liberality of the Members of the profession, that favourable reception they might not otherwise have experienced. It only depended on the Members to extend this sphere of utility, and to connect the Institution with the records of the great works distinctive of the nineteenth century.

The remainder of Mr. Manby's days would probably have been passed in the prosecution of these views, but events were otherwise ordered, and since his resignation as paid Secretary had been tendered and accepted, he had again to be grateful to a kind friend, a Member of the Profession, for obtaining for him that which he valued most highly,—his present connection with Mr. Robert Stephenson, the excellent President.

The value of the Testimonial with which the Members and his Friends were pleased to recognize his willing services, was greatly enhanced by the kind feeling which prompted it, and the alacrity with which the proposition had been met; he should look upon it with pardonable pride, not only as a mark of the approbation and the friendship of the Members, but as reminding him of the Institution, with which it had been his ambiton to be permanently identified; and he now asked as a favour to be permitted to devote a portion of the amount of the Testimonial to establishing an Annual Premium which should bear his name.

There was another point on which he would say a few words;—the Engineering Profession reckoned among its numbers many rich and prosperous men, but there were also many less fortunate Members, to whom aid in time of sickness, or need, or succour to a struggling and bereaved family, would be inestimable. Yet the Engineers were the only professional body not possessing some kind of a mutual aid society. Would it not be possible to originate some plan for thus doing good? His time and means might be freely commanded, and he should feel happy in devoting to such an object a further portion of that which had been so generously placed at his disposal.

It only remained for him to renew his heartfelt thanks, not only for the munificent present, but for the kindness and friendship with which he had been favoured during so many years. To the past

Presidents—the actual President—the Council, and the Senior Members, he was deeply indebted for countenance, support, and advice, and to the Junior Members, whose interests had ever had his best care, he owed much, for their cheerful co-operation and the confidence they had ever reposed in him. He had only inadequately expressed his thanks, but they would give him credit for the sincerity of his feelings, and as long as his services could be made available to the Institution, or to the Members, within those walls, or elsewhere, they might be freely commanded.

Mr. JOSEPH LOCKE, M.P., Vice-President, proposed a vote of thanks to the President for having taken the chair on the occasion, and having so kindly expressed the unanimous feelings of the Members towards their valued officer and friend, to whom they all wished every prosperity in the career in which he was now embarked.

The Members and their friends then adjourned to the "Ship," Hotel, at Greenwich, where they had invited Mr. Manby to dine.

Mr. Robert Stephenson, M.P., President, occupied the chair, and after an excellent repast in Mr. Quartermaine's best style, he proposed the usual loyal toasts, observing that there was not any profession more loyal in its attachment to the throne than the Engineers. They would recollect that during the reign of Her Majesty some of the greatest works had been achieved, and the advent of His Royal Highness the Prince Consort was contemporaneous with the greatest advance in engineering science; so, also when the services of Civil and Mechanical Engineers had been required, during the late war, they were freely given, in a novel field, and had been eminently successful.

In proposing the principal toast of the occasion, the Chairman said he had already imperfectly expressed his own feelings and those of every Member of the Institution, with regard to the eminent services rendered by their friend, Mr. Manby, during so many years. He was sure that there was not an individual in the room, or belonging to the Society, who had not experienced in some manner his kindness and urbanity.

As a Senior Member he had very often derived advantage from the services so willingly rendered; but it was the Junior Members especially, who were most deeply indebted to their consistent friend, the Secretary, as he never lost sight of their interests, was ever at their service, and appeared to consider their advancement a paramount duty. In fact, all classes owed him much, especially for his exertions in bringing them more frequently together within the walls of the Institution, where in assembling for the promotion of

the general good of the profession, they obliterated the feelings which were sometimes engendered by the violent professional contests in which they had all been engaged. Mr. Manby had originally undertaken a difficult task; it was essential to win the confidence of all around him, and then to use the power with discretion; this he had done most successfully, devoting himself to reconciling these differences that must occur, and rendering the Institution almost indispensable to the profession. He had no hesitation in saying, that the present position of the Society was almost entirely to be attributed to the exertions and skill of his friend Mr. Manby, whose health and prosperity he begged to propose.

Mr. MANBY, in responding to the toast, said, if he had at a former period of the day experienced difficulty in expressing his feelings, that difficulty was now augmented by the kind terms in which the Chairman had mentioned him. He feared that more than just praise had been bestowed on him, for having endeavoured honestly and faithfully to perform his duty; he had been fortunate in having the direction and advice of a Council comprising the most eminent Members of the Profession, who had always given him their frank co-operation. It was a laudable object of ambition on the part of the Junior Members to be admitted to the Council, and he was proud to see around him many who, if they continued in the course they had so well began, would worthily succeed the seniors, when they retired with their honours full upon them.

He would avoid repeating what he had said at an earlier period of the day, when they had presented him with a Testimonial which he should always look upon with pride and satisfaction; but he could not help entreating them never to lose sight of the Institution, which had been and would still be the means of conferring the greatest benefit upon the Profession, to which all were proud to belong.

He begged again to thank all his friends for their unvarying kindness, and without, he hoped, making any invidious distinction, would especially thank his excellent friends Mr. Bidder, Mr. McClean, and Mr. Doyne, for their active exertions in the matter of the Testimonial, and his friend and former pupil Mr. Forrest, who he had much pleasure in seeing appointed as Assistant Secretary and eventual successor. He was convinced that if they extended to Mr. Forrest the same kindness and confidence they had shown to him, everything would be done to promote the interests of the Institution, and to enlarge its sphere of usefulness.

Although he had now retired from the position of paid Secretary, and the more active official duties had devolved upon Mr. Forrest, it had been considered desirable that he should still retain the title of Secretary, and perform the duties. He felt great pride in receiving this additional mark of the confidence of his kind friends,

and he begged them to believe that his best efforts should at all times be freely at their command.

The CHAIRMAN, again requesting attention, said the few toasts he would propose should be confined to subjects strictly within the province of the Institution. During the period of his Presidency several excellent subjects had been brought before the meetings, but there was one which had excited more than ordinary interest —he alluded to the remarkable lectures by his esteemed friend Mr. Bidder, on "Mental Arithmetic." They were all aware of the extraordinary powers of their friend, but it was not believed that he could have explained, so clearly, the mental processes by which he arrived at the results with such rapidity; it had, however, been done with admirable perspicuity; and in a somewhat extended voyage, the Chairman had recently made, he had been gratified by finding, that these extraordinary lectures had penetrated even to Alexandria and Algeria, and had everywhere excited the most lively interest. He would ask them to drink the health of their friend Mr. Bidder, V.P., with thanks for his long-continued and valuable services to the Institution.

Mr. BIDDER thanked his friends sincerely for their reception of his name, and he felt especially gratified by the complimentary manner in which the Chairman had mentioned the attempt which he had made to explain his process of Mental Arithmetic; he had long intended to bring that subject before the Members, but had reserved it for the presidency of his old friend Mr. Stephenson, and he felt highly gratified that his exertions had been considered useful to a Society in whose welfare he had always felt great interest.

With respect to the special object of their meeting, the alacrity with which the proposition of the Testimonial was universally received, was such that his task as Treasurer became comparatively easy; he was in the position of a coachman with a willing, or rather an over-free team, needing the curb and the drag, rather than the whip; the result was peculiarly gratifying to him, and he added his best wishes to those which had been so deservedly expressed to their worthy friend the Secretary.

It was about thirty years since Mr. Bidder joined the Institution, and if he had a reproach to make, it was that the Members did not, so frequently as they ought, have social gatherings which must conduce to their mutual good. When the number of Members was very small, they frequently dined together, and this day's proceedings showed that a larger number could meet with equal satisfaction, and he was certain it would conduce to the good of the Institution.

Mr. JOSEPH LOCKE, M.P., V.P., said he was permitted to propose a toast which, he was assured, would be received with enthusiasm;

it was the health of that excellent man and distinguished Engineer, Mr. Robert Stephenson, who now so worthily presided over the Institution, whose Members had this day done themselves honour in recognising the valuable services of their old friend Mr. Manby, on behalf of the Society. That the Institution well merited the most strenuous efforts they would all admit, and that the efforts had been attended with complete success, the proceedings of the day amply proved, and the Testimonial offered to Mr. Manby showed how fully they appreciated his services.

He had heartily concurred with the Chairman, in his remarks as to the advance of Engineering science during the reign of her present Majesty; and he rejoiced that in this country they were permitted to exercise their professional duties unfettered by Government interference. This might be approaching a dangerous topic, but he had often before given his opinion, and it had been cordially received. Looking around the room, and observing the intelligence, skill, and talent embraced by the Institution, he felt great pride in belonging to a Society, the labours of whose Members were universally known and appreciated, and who were individually the missionaries of civilization throughout the world. This position could scarcely have been reached, but for the Institution, which attracted towards it all that mental power and practical skill, which, when combined, conduced so materially to the nation's wealth and the people's prosperity.

Reverting to the toast he had the honour to propose; no man occupied a more prominent position than their excellent President, and no man was more worthy of that position. His history was that of most of the great men of this country: he had sprung from the ranks of the people, and by his own efforts alone, he attained his present high reputation, and established a fame which was indissolubly connected with the greatest works of the present period. He would give them the health of Mr. Robert Stephenson, President of the Institution of Civil Engineers.

Mr. Robert Stephenson, in returning thanks, cordially subscribed to all that had fallen from Mr. Locke, with respect to the advantages afforded by the Institution, in bringing together men of intelligence and skill, and conferring great benefits upon the Profession generally; but more especially in allaying that effervescence of feeling engendered by professional contests, which were now conducted in a spirit to induce mutual respect and esteem. He regretted the absence of his friend, Mr. Brunel, with whom he had maintained arduous struggles, which he could now look back upon with such pleasure as almost to desire to fight again "The Battle of the Gauges."

Mr. Field, Past-President, said, as one of the founders of the Institution, and now, he believed, the oldest Member, he well

recollected the time when their meetings were at such long intervals and their number of members was so small, that their ultimate success appeared to be very problematical. Their great difficulty was to find a Secretary combining all the qualifications they required, because such a man must possess engineering knowledge and other talent which would enable him to embark in a more profitable career. They tried many good men, and he had despaired of ever finding the proper man, until at length his old friend Mr. Manby was prevailed upon to take the position, and for the last eighteen years they had all witnessed the success of his efforts.

The results, from so small and unpromising a beginning, had astonished, as much as they had gratified him. They were now entering on a new phase of the existence of the Society. Mr. Manby had partially withdrawn from the post of Secretary, with honours which he hoped would long be enjoyed, and they had in prospect, as his successor, a gentleman who was well known to them from his long association with Mr. Manby, as his pupil, and who appeared to be also just the person they wanted. He begged to propose, "Success to the Institution of Civil Engineers," coupling with it the name of Mr. James Forrest, the Assistant Secretary.

Mr. FORREST said, that through the kindness of his friend Mr. Manby, he had been incidentally connected with the Institution for nearly fourteen years, and by the Council he had been selected to succeed to the office which had been so long and so ably filled, as to merit the demonstration of the day. He only hoped that when he assumed the position with all its responsibilities, he might, by following the footsteps of his predecessor, equally merit their confidence; he should try to do so, and with their kind assistance he trusted to perform the duties of the post so as to promote the best interests of the Society.

Mr. GLYNN begged permission to propose "Success to the Great Eastern Steam Ship," coupling with the toast the name of Mr. Scott Russell.

Mr. J. SCOTT RUSSELL said he was undoubtedly proud of being the builder of the great ship, and should feel still prouder if she achieved the success he ventured to anticipate. The most remarkable feature connected with it was that a body of men should be found who would subscribe £700,000 for an undertaking, the success of which was declared to be very problematical; that feeling would, however, be diminished when it was known that three-fourths of the shares in the undertaking were held by Members and Associates of the Institution of Civil Engineers. That fact alone spoke volumes for the safety of the structure. Mr. Brunel, who must be called the Father of the project, had desired to have the smallest ship capable of taking its own fuel to Australia and back, and of conveying such a cargo of goods

and passengers as should be remunerative. Calculation showed the actual dimensions to be necessary, and the system of cellular construction, adopted from the example of the Britannia Bridge, afforded the strength for these vastly increased proportions, which had at first surprised even English Engineers, with their habits of regarding everything as possible. The size did not now, however, astonish even the merchants, who contemplated finding cargoes for her without trouble. It would be a proud day both for Mr. Brunel, (whose absence he regretted,) and for him, when the "Great Eastern" was committed to her proper element. The ship was a specimen of what the combined qualities of men could produce, and it impressed upon all the advantages of such union as the Institution afforded the means of encouraging. United they could do almost anything, and their efforts must benefit their country, and be conducive to their own good.

The President then quitted the chair, and every one retired early, well satisfied with the appropriate conclusion of the proceedings of the day.

BALANCE SHEET.

To Subscriptions. . .	£2,126	3	0	By Cash to C. Manby. .	£2,020	16	7
To Deposit Interest . .	23	12	0	„ Balance of Dinner Account	14	19	0
				„ Clock and Candelabra .	84	0	0
				„ Printing and Lithography	15	9	6
				„ Postage, Receipt Stamps, and Stationery . . .	14	9	11
	£2,149	15	0		£2,149	15	0

We have examined the Receipt Books of the Manby Testimonial Fund, and also the Vouchers for the several payments, and find the above Statement of Accounts to be correct.

(Signed) WILLIAM POLE,
T. MACDOUGALL SMITH.

12*th April*, 1858.

LIST OF SUBSCRIBERS TO THE MANBY TESTIMONIAL.

HONORARY MEMBER.

EARL OF ROSSE.

MEMBERS.

Abernethy, J.
Amos, C. E.
Armstrong, W. G.
Ashwell, J.
Baker, W.
Bampton, A. H.
Barlow, P. W.
Barlow, W. H.
Barry, F.
Barton, J.
Bateman, J. F.
Bazalgette, J. W.
Beamish, R.
Beardmore, N.
Beattie, J. H.
Berkley, G.
Berkley, J. J.
Bertram, T. H.
Beyer, C. F.
Bidder, G. P.
Blackadder, W.
Blackburne, J. G.
Blackwell, T. E.
Blakiston, M.
Blyth, B. H.
Bridgeman, H. O.
Bruce, G. B.
Bruff, P.
Brumell, C.
Brunel, I. K.
Brunlees, J.
Brunton, J.
Buddicom, W. B.
Burges, A.
Butler, J. O.
Carpmael, W.
Carr, H.
Casebourne, T.
Cawley, C. E.
Cheyne, C.
Clark, E.
Clegram, W.
Colthurst, J.
Conybeare, H.
Coode, J.
Cooper, J.
Crampton, T. R.
Cubitt, J.
Cubitt, Sir William
Daglish, R.
Davison, R.
Dees, J.
Dixon, E.
Dobson, G. C.
Dobson, S.
Dockray, R. B.
Doyne, W. T.
Drane, T.
Drysdale, A.
Duncan, T.
Eckersley, W.
Edwards, H. H.
Elliot, G.
Errington, J. E.
Fairbairn, W.
Fenton, J.
Field, J.
Flachat, E.
Flanagan, T.
Forsyth, J. C.
Fowler, J.
Froude, W.
Garrett, R.
Gibb, A.
Giles, A.
Giles, G.
Glynn, J.
Gooch, J. V.
Gooch, T. L.
Grantham, R. B.
Gravatt, W.
Gregory, C. H.
Hardwick, P.
Harrison, G.
Harrison, J. T.
Harrison, T. E.
Hartree, W.
Harvey, N.
Hawkshaw, J.
Hawksley, T.
Haywood, W.
Hemans, G. W.
Hensman, H.
Heppel, J. M.
Hick, J.
Higinbotham, T.
Hood, R. J.
Hughes, J.
Hurwood, G.
Jee, A. S.
Jones, Sir H. D.
Jones, J.
Kennedy, J. P.
Kitson, J.
Lane, C. B.
Lanyon, C.
Le Fanu, W. R.
Lindley, W.
Lloyd, T.
Locke, J.
McClean, J. R.
McConnell, J. E.
McLandsborough, J.
Macdonnell, J. J.
Mackintosh, A.
Mackworth, H.
Mallet, R.
Manby, E. O.
Manby, J.
Manby, J. L.
Marten, H. J.
Martin, A.
Matthew, J.
Maudslay, H.
Maudslay, J.
May, C.
Meredith, G.
Miller, G. M.
Miller, J.
Mitchell, J.
Murray, J.
Nepveu, C. M. A.
Newlands, J.
Nixon, C.
Norris, R. S.
Oldham, J.
Page, T.
Parkes, J.
Peacock, R.
Peel, G.
Penn, J.
Penson, T.
Phipps, G. H.
Plews, J.
Pole, W.
Preston, R. B.
Provis, W. A.
Quick, J.
Radford, W.
Ramsden, J.
Redman, J. B.
Rennie, G.
Rennie, Sir John
Rhodes, T.
Richardson, J.
Richardson, R.
Roberts, R.
Robertson, H.
Russell, J. Scott
Samuel, J.
Simpson, J.
Simpson, W.
Slaughter, E.
Smith, A.
Smith, T. M.
Sopwith, T.
Stephenson, R., M.P.
Stephenson, G. R.
Stileman, F. C.
Struvé, W. P.
Swinburne, W.
Taylor, J., jun.
Thomson, J.
Thomson, J. G.
Tone, J. F.
Valentine, J. S.
Vignoles, C.
Vigors, T. M.
Walker, J.
Watson, J.
Weallens, W.
Whitworth, J.
Wicksteed, T.
Wood, N.
Woodhouse, J. T.
Woods, E.
Wright, J.
Wynne, T.
Yarrow, T. A.
Young, F. M.

ASSOCIATES.

Adams, E.
Adams, W.
Aickin, G.
Allan, J.
Appold, J. G.
Arntz, R. R.
Atkinson, J. S.
Attwood, M. W.
Bagot, E.
Barrett, J.
Bell, T. (Newcastle-on-Tyne)
Bergue, C. L., A. de
Bethell, J.
Betts, E. L.
Bevan, W.
Biddell, G. A.
Bird, W.
Botfield, B., M.P.
Boulton, S. B.
Boutigny d'Evreux, P. H.
Boyd, J.
Bramwell, F. J.
Brassey, T.
Brounger, W. G.
Burleigh, B.
Burt, H. P.
Bury, T. T.
Cammell, C.
Cayley, Sir Geo. Bart.
Chadwick, D.
Church, J.
Clark, D. K.
Claxton, Capt., R.N.
Clutton, J.
Cochrane, A. B.
Cochrane, J.
Collins, W. W.
Corlett, C. H.
Coulthard, W.
Cowen, R.
Cowper, E. A.
Croker, B. W.
Croll, A. A.
Crosland, W. M.
Crosley, E.
Crosley, W.
Cubitt, L.
Curtis, J. G. C.
Daglish, R., jun.
Denton, J. B.
Dickinson, J.
Donaldson, G.
Doull, A.
Downing, S.
Drew, E. A.
Dunn, T.
Dykes, D. S.
Enys, J. S.
Estridge, Lieut.-Col. B. E.
Etty, Thos. B.
Evans, F. J.
Exall, W.
Falshaw, J.
Ferrieres, A. de
Forrest, J.
Francis, C. L.
Freeman, J.
Freeman, W.
Frodsham, C.
Galton, Capt. R.E.
Gardner, J.
Garrett, R., jun.
Goddard, E.
Graham, J.
Grissell, H.
Grissell, T.
Grove, E.
Guppy, T. R.
Gutch, G.
Hamilton, J., jun.
Hanvey, J.
Harratt, C.
Hedley, T. A.
Heinke, C. E.
Heinke, J. W.
Henderson, A.
Henderson, J.
Highton, E.
Hill, J.
Hobbs, A. C.
Hobbs, W. F.
Holland, W. H.
Hooper, H.
Houldsworth, J.
Howard, T. (Rotherhithe)
Humber, W.
Huish, Capt. M.
Hunt, H. A.
Jackson, R. W.
James, J.
Jay, J.
Johnson, R.
Johnson, T. M.
Jones, J. H.
Kennard, R. W.
Kennard, T. W.
Knight, G.
Knight, S. J.
Lambert, T.
Lawrence, F.
Lancaster, C. W.
Leather, J. T.
Linn, A. G.
Lloyd, S.
Lovelace, Earl of
McKerlie, Lt.-Col., R.E.
Malins, W.
Marrable, F.
Marshall, E.
Marshall, J. G.
Matthews, W. A.
Maxwell, W. H.
Metford, W. E.
Mills, G.
Molesworth, G. L.
Moulton, S.
Newton, W.
Ogilvie, A.
Owen, W.
Parkes, W.
Parsons, J. M.
Parsons, P. M.
Paxton, Sir J., M.P.
Pearse, G.
Peirce, J. S.
Peto, Sir S. M., Bart.
Piper, T., jun.
Piper, W.
Pooley, H.
Porter, J. H.
Price, E.
Rankine, W. J. M.
Ransome, F.
Ransome, J. A.
Ransome, R.
Rawlinson, R.
Reed, R. F.
Rennie, G. B.
Ridley, T. D.
Rigby, C.
Rigby, J. D.
Robertson, G.
Robinson, H.
Robinson, H. G.
Robinson, R. A.
Roe, J. P.
Roney, Sir C. P.
Rosser, S. E.
Saunders, G. H.
Scott, W. B.
Selby, G.
Sewell, J.
Sheilds, F. W.
Sheppard, F. A.
Siebe, A.
Siemens, C. W.
Simms, W.
Slate, A.
Smith, J. P.
Smith, F. P.
South, T. G.
Stephenson, Sir R. M.
Stevens, J. J.
Stockman, B. P.
Strode, W.
Swann, W.
Taylor, J.
Taylor, W.
Thomson, D.
Treherne, E.
Trickett, J.
Turner, R.
Upward, A.
Vaughan, J.
Waring, C.
Waring, H.
Warriner, H.
Watson, W.
Webb, W. L.
Western, Lieut.-Col. B. E.
White, G. F.
White, J. B., jun.
Wilkins, W. C.
Williams, A.
Williams, C. C.
Williams, C. W.
Williams, M. B.
Wilson, E. B.
Winder, T. R.
Window, F. R.
Wood, S.
Wordsworth, C. F. F.
Wright, A.
Wright, T.
Wyatt, M. D.
Wyatt, T. H.

GRADUATES.

Baker, W. L.	Birch, J. B.	Jeakes, W.	Tucker, J. S.
Birch, E.	Evill, W., jun.	Jermyn, G. A.	

PRIVATE FRIENDS.

Adams, W. B.	Cutts, W. W.	Johnson, Mrs.	Robinson, W.
Ashbury, I.	England, G.	Johnson, Miss	Smith, R.
Ashcroft, P.	Fishe, C. C.	Johnson, T.	Snowden & Hopkins
Baillie, J.	Franc, J. Le	Kreeft, S. C.	Spencer, J.
Barber, W.	Grissell, M.	Lefferts, Col. M.	Stephenson, F.
Barlow, Capt. J.	Healey, E. C.	Lewis, W. B.	Sutton, I.
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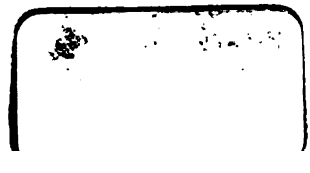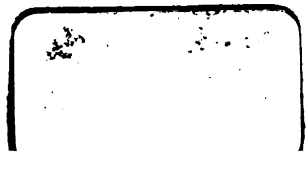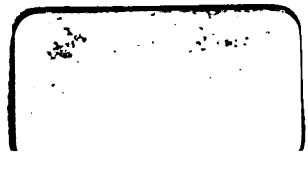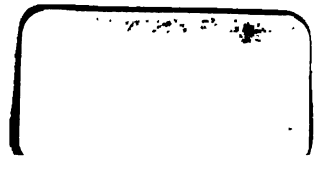
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